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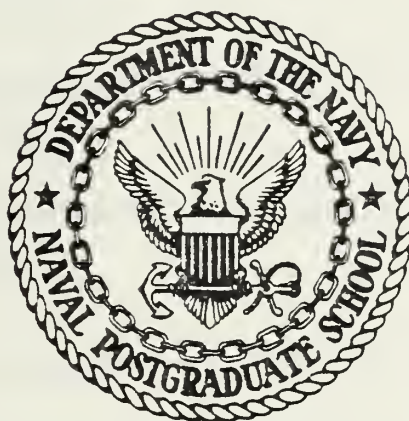
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A HOMING TORPEDO
THE EFFECT OF THE TACTICAL SITUATION
AND THE TORPEDO PARAMETERS
ON THE TORPEDO EFFECTIVENESS.

Anders Mjelde

NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

A HOMING TORPEDO.

THE EFFECT OF THE TACTICAL SITUATION AND THE
TORPEDO PARAMETERS ON THE TORPEDO EFFECTIVENESS

by

Anders Mjelde

September 1977

Thesis Advisor: A. R. Washburn

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PARAMETERS
ON THE TORPEDO EFFECTIVENESS

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the
NAVAL POSTGRADUATE SCHOOL
September 1977

ABSTRACT

When designing an active sonar homing torpedo, certain operational torpedo parameters such as speed, turn rate, etc. have to be decided upon. For a given homing torpedo, there must exist tactical guidelines of how to employ the torpedo, i.e. which firing position gives the best chance of a hit. This thesis attempts to gain some insight into the detection process during the torpedo run, as well as getting some indications of the relative importance of the different torpedo parameters and the tactical situations. A simulation model was used in order to generate the data base for analysis. The results stress the importance of a good firing position as well as show how it is possible to counter a bad firing position by a high speed torpedo. They also point to the importance of having only one detection as requirement for target acquisition.

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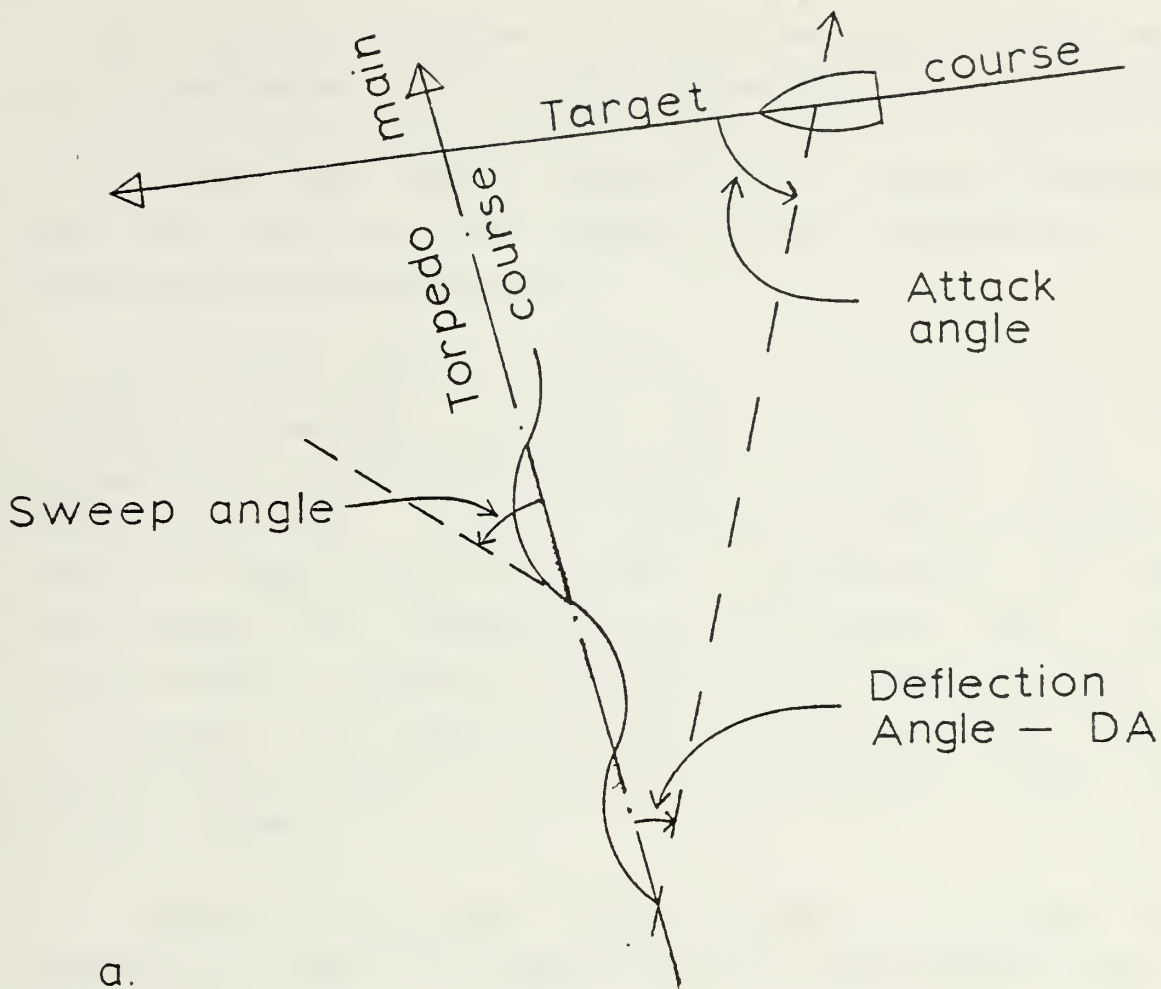
I. INTRODUCTION

The following analysis examines the performance of a homing torpedo against a surface ship. A homing torpedo is described as a torpedo which is searching/snaking on each side of its main course. It is searching for a target by transmitting with its sonar and listening for an echo. Ref. Fig. 1. Passive searching torpedoes and homing torpedoes going in circles are not investigated in this paper.

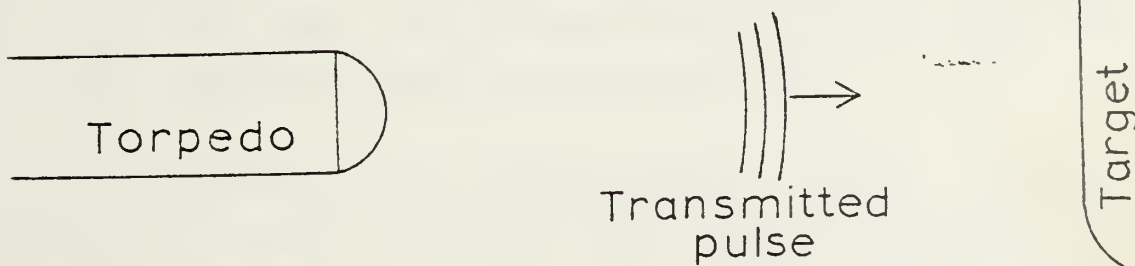
The torpedo's performance is a function of many variables. These variables are divided into two groups;

- technical variables; speed, max torpedo run, sweep angle, technical detection range, lobe characteristics and turn rate.
- tactical variables ; firing range, attack angle, target speed, type of target and tactical detection range (sonar conditions).

No attempt is made to analyze the first group of variables; instead, technical variables used are those of present technology. We are assuming a 'standard homing torpedo' based upon homing torpedoes in operational use today [8]. This 'standard torpedo' assumes conventional warhead and active sonar transmission for detection., and is unguided.



a.



b.

Figure 1 - A HOMING TORPEDO

The technical variables (torpedo parameters) are in many ways interrelated. For example, the maximum detection range will determine the transmission rate, since the transmitted energy must have time to traverse out to maximum detection range and return as an echo before the next transmission, at least during the search phase.

At the same time the torpedo is transmitting, it is searching (changing course) for a target. In each transmission, the transmitted energy is focused within a narrow beam(lobe). During reception, the echo is confined within the same narrow beam(lobe). Concurrently, in the time between two transmissions the turning rate of the torpedo must be limited to ensure that the receiving lobe is not outside the direction from where an echo may return. Thus turn rate should be a function of detection range and the lobe pattern.

In order to maintain torpedo speed, the number of degrees of sweep on each side of the main course must be small. If the sweepangle is small, however, the width of the possible detection lane will be small as well, and consequently the detection probability might be reduced during transit. Also, a high torpedo speed creates a great change in torpedo position between each transmission. In this way the torpedo may scan outside a target in the sweep lane. In other words, the coverage density of the lobe may be low as a result of the high movement rate.

As we recognize the relationship between torpedo parameters, tactical variables and torpedo performance, we know that frequently within the naval establishment decisions have to be made with regard to torpedo parameters and tactical doctrines. In localizing and defining these relationships this analysis may be a tool in this

decisionprocess.

The measure of effectiveness by which different alternatives will be judged will be detection probability, by which is meant the probability that the torpedo's active sonar detects and begins to track the target. This probability will be measured by a digital computer simulation, construction of which was a major part of the author's effort in writing this thesis.

II. NATURE OF THE PROBLEM

A. DEFINITIONS

Lobe width is the number of degrees from the centerheading of the torpedo, until the first minimum in transmission intensity is reached. See Fig. 4.

Detection range is the range to the target when detection first occurs.

Technical detection range is the max detection range which is technically and reasonably possible considering power transmitted and lobewidth. It is the basis for determining the transmission rate.

Aspect is the angle measured from the positive direction of the longitudinal axis of the target to a line joining the centers of gravity of the target and the torpedo.

Attack angle is the aspect at the start of the torpedo run.

Sweep angle is the maximum number of degrees the torpedo will turn off the main course during search.

All dimensions are in meter, second, meter per second, degree, degree per second. Speed of the target and the torpedo are, however, always given in knots.

It is assumed that all firings are successful, and the torpedo will not deviate from its ordered/calculated course and speed.

All firings are made with a deflection angle; i.e. the torpedo is given a course to a predicted hitting point with the target.

B. ASSUMPTIONS

Not only in order to keep the problem tractable, but also because of modern torpedo development, only surface targets are considered. Previously within NATO, torpedo developments seemed to start as a development of an anti-submarine torpedo with later modifications in order to make the torpedo dual purpose. However, today there are some indications that the anti-surface ship requirement is coming into the development early in the planning process [7;8;9]. The entire problem is then kept in two dimensions. The vertical axis is not significant as we assume isovelocity condition, and we assume for simplicity that we have negligible surface effect.

Also, if the intensity of the echo is above detection threshold level, the target is detected with probability one. Probability of false contact is assumed to be zero.

The main purpose of a homing torpedo is to counter uncertainty in target data at firing and target maneuvering after firing.

For simplicity the following assumptions are made:

- the target remains on a steady course after firing.
- estimated target data is used in solving the deflection angle problem

- deflection angle(DA) is given by;

$$DA = \text{ARCSIN}((TAM \times \text{SIN}(ASP))/TO) \quad (2.1)$$

TAM = target estimated speed
 ASP = estimated aspect
 = (target estimated course) -
 (bearing to torpedo)
 TO = torpedo speed.

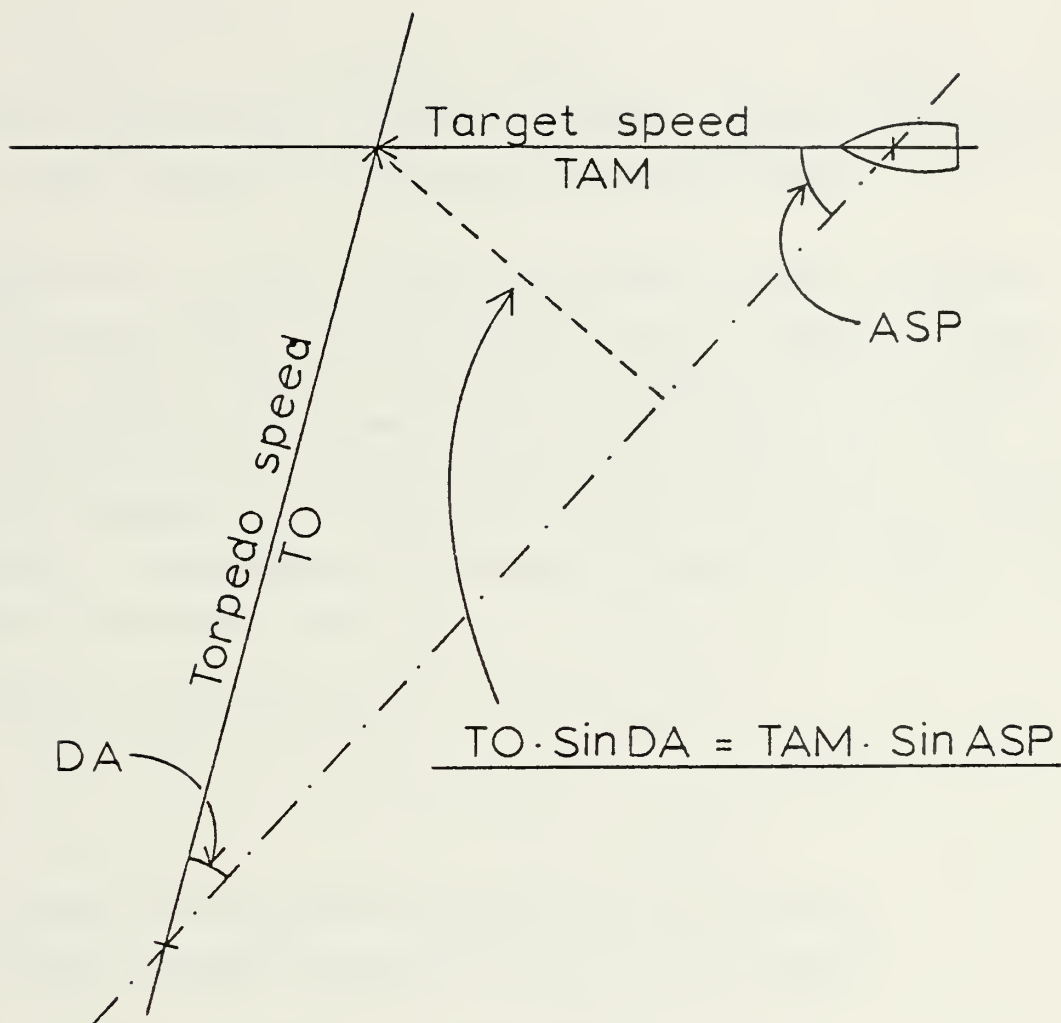
See Fig. 2.

The difference between the target data and the target estimated data are defined as errors in the target data. These errors are assumed to be random variates and are given as;

- target range error is uniformly distributed between
 - 15 % and + 15 % of actual target range
- target course error is uniformly distributed between
 - 15 and + 15 degrees
- target speed error is normally distributed with mean
 0 and standard deviation 3 knots.

These errors are assumed to cover errors in the fire control solution at the time of firing as well as non-radical maneuvering of the target during the torpedo run.

As shown in Eq. 2.1, estimated range does not enter into the calculation. Estimated range would only be used for some more complicated tactical situations as angled torpedo firing off the firing course of the firing unit. These situations are not covered in this study.



ASP — Estimated Attack angle

DA — Deflection angle

Figure 2 - TORPEDO TRIANGLE

III. PROBLEM SOLVING APPROACH

At firing, the initial course of the torpedo is uniformly distributed between minimum course and maximum course (main course +/- a fraction of sweep angle).

Immediately after firing, the torpedo starts 'snaking'. During snaking, the torpedo is continuously changing course left or right out to the given sweepangle, then back past main course and out to sweepangle on the other side and so on. The torpedo is turning with the given turnrate. During the whole process, the torpedo is also transmitting and listening. Transmission interval(TTIME) is given by technical detection range as;

$$TTIME = 2 \times TEDEC / 1500 \quad \text{seconds} \quad (3.1)$$

where

TEDEC = technical detection range in meters.

1500 = speed of sound in salt water, m/sec.

The torpedo run is conducted in steps. Every 0.5 seconds interval, all positions and courses are updated.

At each transmission; the relative bearing to target, and the target aspect are calculated in order to establish the intensity of the echo.

When a detection occurs, the following data is stored;

- detection range to the center of the target.

- detection range to the nearest part of the target.
- detection bearing (relative) to the center of the target.
- detection bearing(relative) to the nearest part of the target.
- target aspect.

In addition to the detection probability, the range at which the detection first occurs is also of interest. Therefore, we store these data at the first detection.

However, successive detections are also important. As part of the criterion for the decision of when to go from search-phase to attack-phase, the number of successive detections (with no non-detection between) may be employed. In real life there is always a positive probability of false detection. Even if we are not addressing the problem of false contact as such, we can cover the possibility by requiring the torpedo to have at least two successive detections before going into attack-phase. Accordingly, we store also the previously listed data at the second successive detection(two immediately following detections), at the third and so on, up to and including 5 successive detections. This listing of detections will give an indication of the decrease in detection probability if a large number of successive detections before going into attack-phase is required in order to decrease the probability of false contacts.

IV. MODEL

A. SEARCH

For simulating the torpedo search, a Fortran IV simulation program was developed.

The program was divided into;

- Main program, including generation of statistics and print out of summary after all the runs were completed.
- Subroutine PARMET for setting tactical situation and torpedo parameters.
- Subroutine FIRING which calculates estimated target data, and the deflection angle.
- Subroutine POSIS which calculates the torpedo course, and torpedo and target positions at each time step.
- Subroutine DETECT which checks if the target is detected and if so, store detection data.

See Fig. 3.

See Appendix A and Appendix B.

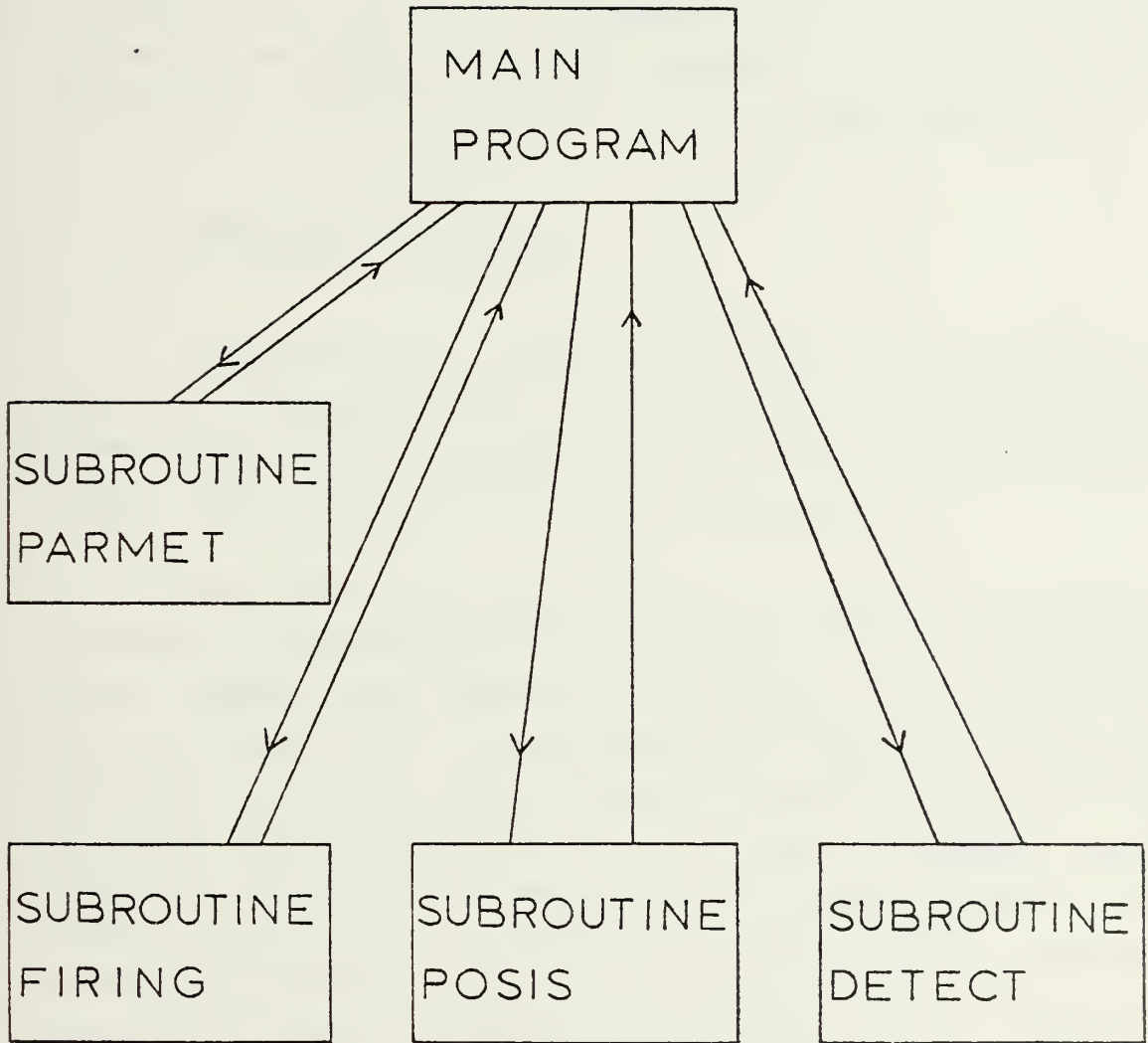


Figure 3 - STRUCTURE OF COMPUTER PROGRAM

B. DETECTION MODEL

A contact occurs when the acoustic energy-pulse generated at the transducer and reflected from the target as an echo, is at or above threshold level. In the following discussion we assume that the contact meets the tactical requirement, and accordingly we use the term detection.

1. Detection Threshold

Deciding if a detection occurs is a function of detection threshold(signal to noise ratio), the range to the target, the target strength and the relative bearing to the target, given a level of radiated intensity.

The detection threshold for a torpedo is a function of design and technological sophistication of the torpedo. Without making any assumption about these variables in the model, we start with a given technical detection range, a 'standard' target, and calculate intensity of echo at that range for target aspect equal to 90 degrees(maximum target strength) and relative bearing to the target equal to zero degrees. This echo intensity is then the detection threshold for every transmission during a run. If any echo intensity is above the detection threshold, it is detected; if below the detection threshold, it is not detected.

2. Echo Intensity

In calculating echo intensity we must separately investigate the important factors, which are transducer

gain, lobe characteristic, transmission loss and target strength. The model used is described below.

a. Lobe Characteristics

The transducer has a main lobe and many sidelobes as a function of the transducer's gain and relative bearing. Urlick [6;51-57] discusses some of the different types of beam pattern (lobes), and the following mathematical model was developed and found to give an acceptable pattern;

$$G(\theta) = G_0 \left| \frac{\text{SIN}(x \pi)}{x \pi} \right| \text{COS}(\theta/2) \quad (4.1)$$

where

$$x = \theta/\theta_0 \quad (4.2)$$

and

G_0 = maximum gain

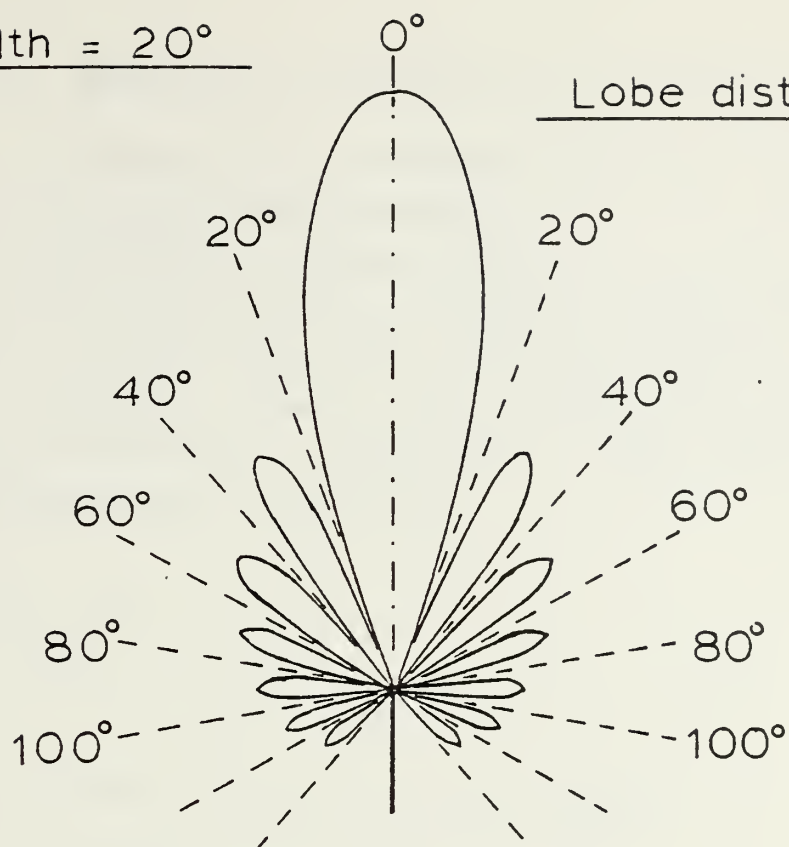
θ = relative bearing

θ_0 = lobe width.

This model will produce the gain-pattern as shown in fig. 4.

Lobe width = 20°

Lobe distribution



Intensity distribution

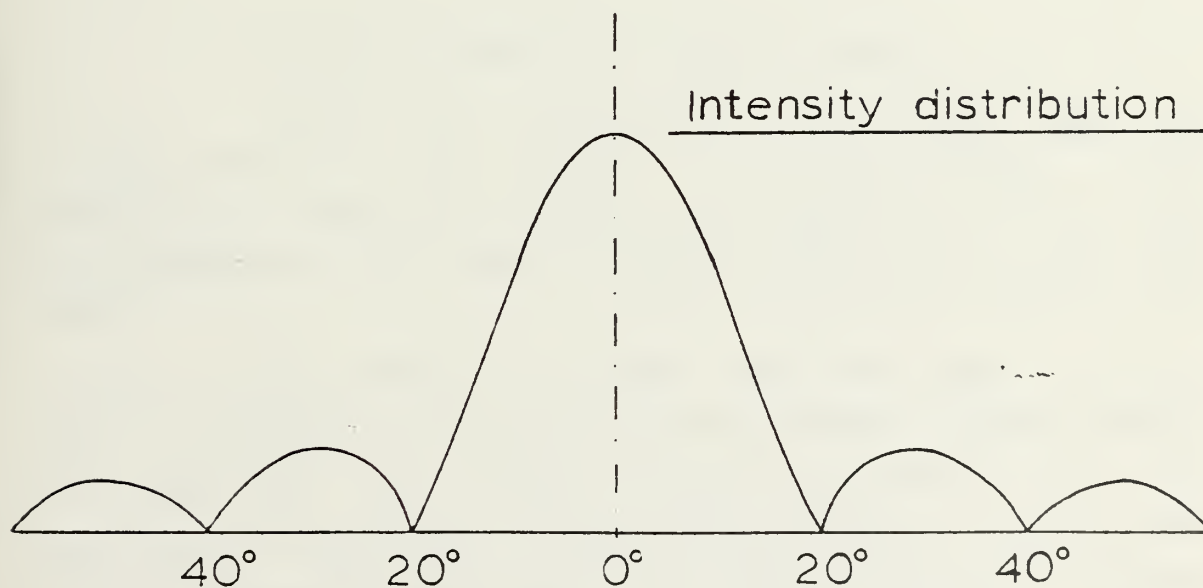


Figure 4 - DISTRIBUTION OF LOBES AND INTENSITY

b. Reduction in Intensity due to Range

Primarily, the reduction is due to two effects; spherical spreading and absorption.

Spherical spreading is a known function, but absorption is dependent upon transmission frequencies, water, salinity etc. In order to simplify the model and since spherical spreading has the greatest effect, only the spherical spreading for reduction in intensity is considered. This reduction in a one way propagation is given by;

$$I = I_0 / R^2 \quad (4.3)$$

where

I_0 = radiated intensity at one meter

I = intensity at range R .

R = range in meters.

c. Target Strength and Target Aspect

When the transmitted energy pulse hits the target, some of the energy is reflected back to the transducer. The echo intensity is a function of the shape and dimension of the target, type of reflective material and aspect.

It should be noted that the notion of target strength represents the ratio between target cross section and the surface of a sphere of radius 1 meter, or if in dB, 10 times the log of this ratio; base 10. In most references, the target strength or the target cross section is given abeam of the target, see [5;97],[6;274], without presenting the cross section as a function of the aspect. Urlick [6;282,283] gives, however, as figures, an indication

of how the target strength(in dB) varies with the aspect. Cox[3;60] states that it will vary between 10 and 25 dB. All measurements in dB in the two references are relative to 1 yard as unit for range. Urick[6;283-286] indicates that his reference (as given in the figures) will not change in any considerable degree with changes in frequencies (20-60 KHz) or for different targets(submarines/surface ships).

Assuming a torpedo with transmitting frequency between 50 and 60 KHz, we get a wavelength varying between 2.5 and 3.0 cm(0.025 - 0.03 meters). As any reflection from a target is mostly determined by target form, size, aspect and wavelength, we may use a model from radar theory in our next step. The justification for this use is that in radar theory we are working in the same area of wavelength and target dimension as an active sonar for a homing torpedo.

Crispin and Siegel [4;86] give for target cross section a model for an ellipsoid where the incident angle(target aspect) is a variable. The relationship is as follows;

$$\sigma = \frac{\pi \cdot a^2 \cdot b^2 \cdot c^2}{(a^2 \cdot \sin^2 \theta \cdot \cos^2 \phi + b^2 \cdot \sin^2 \theta \cdot \sin^2 \phi + c^2 \cdot \cos^2 \theta)^2} \quad (4.4)$$

a, b, c being half axes of the ellipsoid.

Ref. Fig. 5.

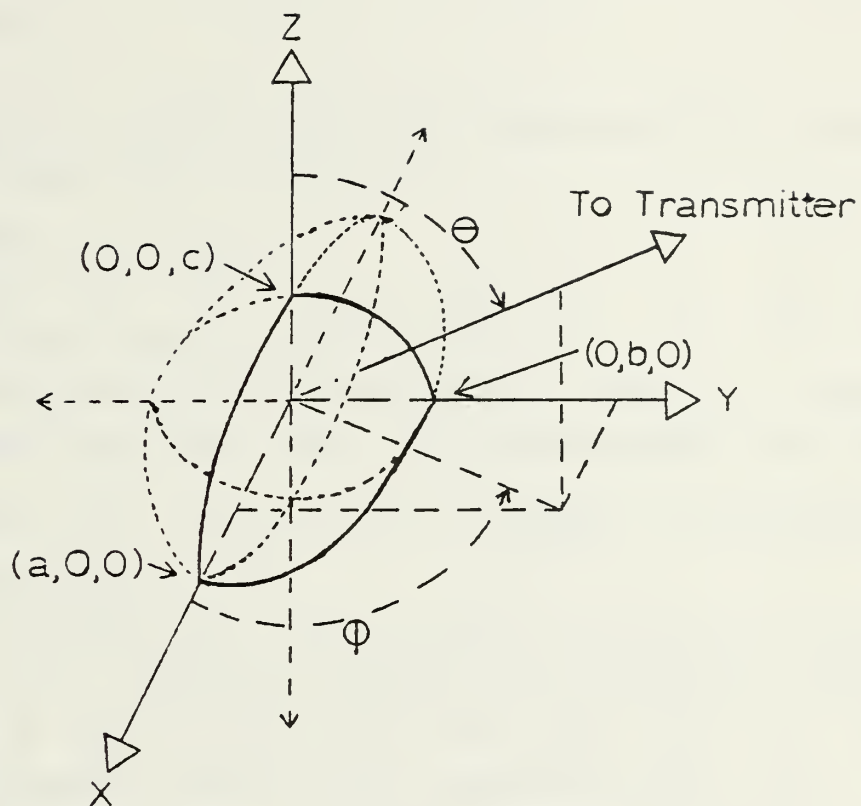


Figure 5 - MODEL OF TARGET AND TARGET ASPECT

As we assume that the transmitting pulse is always in the horizontal plane, θ is 90 degrees, which gives us;

$$\sigma = \frac{\pi \cdot a^2 \cdot b^2 \cdot c^2}{(a^2 \cdot \cos^2 \phi + b^2 \cdot \sin^2 \phi)^2} \quad (4.5)$$

ϕ = aspect.

Urick [6;275] gives for target section a model for abeam or ahead cases, which is;

$$t = \sigma / (4\pi) = (b \cdot c / 2 \cdot a)^2,$$

identical with Eq. 4.5. Note that Eq. 4.5 is an expression for the target cross section.

Haslett [5;139] gives for the target cross section a model for both ahead and abeam cases. His model equals Eq. 4.5 times a factor \underline{R}^2 , where \underline{R} is acoustic reflectivity coefficient (per cent) = 94.

The advantage of using Eq. 4.5 is that it gives the target cross area as a continuous function of the target aspect. For our model we will only use the lower part of the ellipsoid to simulate the ship hull below the water line.

Combining Eq. 4.5 and acoustic reflectivity coefficient we get the following model for the target cross section;

$$\sigma = \frac{\pi \cdot a^2 \cdot b^2 \cdot c^2 \cdot \underline{R}^2}{(a^2 \cdot \cos^2 \phi + b^2 \cdot \sin^2 \phi)^2} \quad (4.6)$$

With reference to Urick's figures [6;283] where the pattern of the target strength is given as a function of

aspect in Fig. 9.13, and reproduced in this analysis as Fig. 6.a, we still have not obtained a model which gives the same type of pattern. By applying the following scaling factor to Eq. 4.6 we have approximated his information:

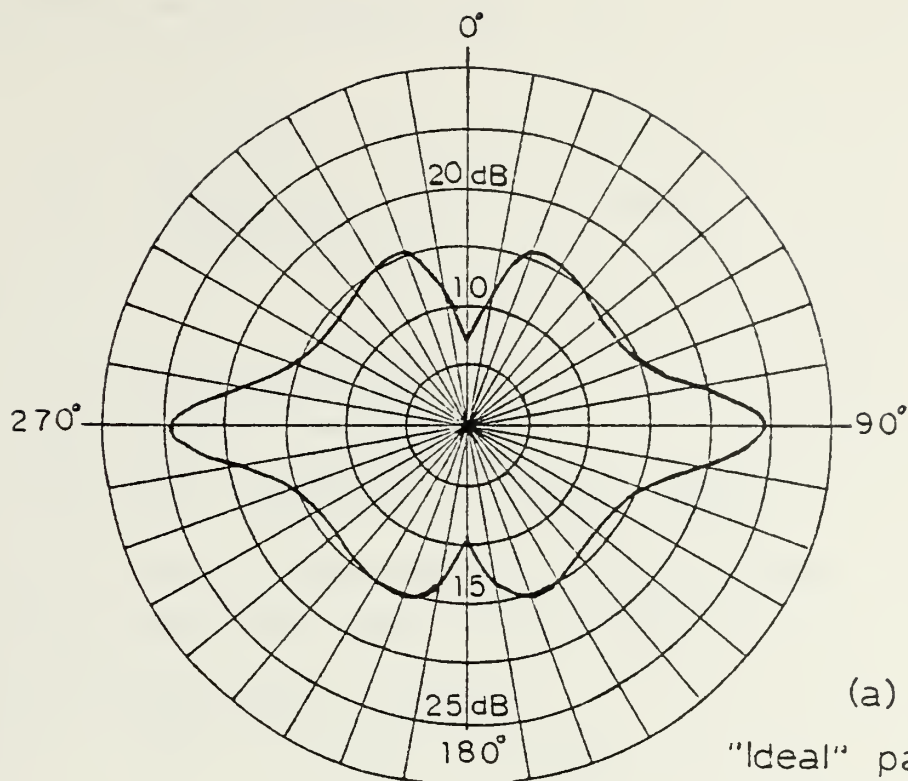
$$U = (0.251635 \cdot \phi^2 - 0.18555 \cdot \phi + 0.0365 \cdot \sin(3 \cdot (\phi + 0.17453))) + 0.015 \cdot \phi^2 \cdot \sin(9 \cdot \phi/2))^{-1} \quad (4.7)$$

We then have as the target cross section in our model the following expression;

$$\underline{\sigma} = \sigma \times U \quad (4.8)$$

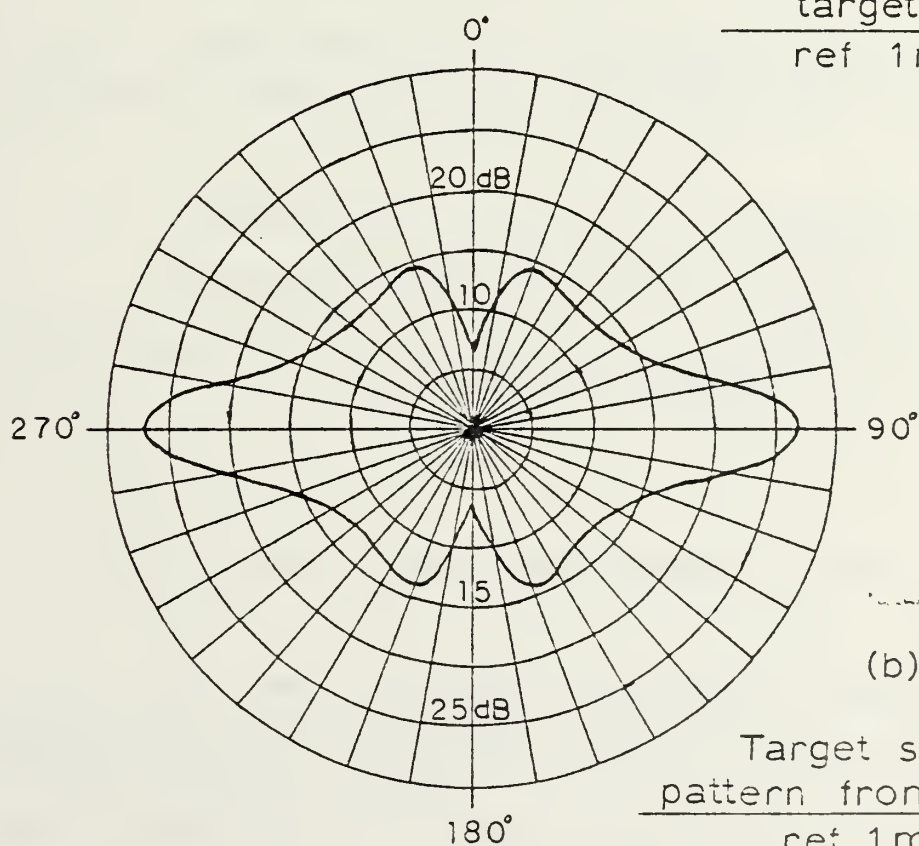
where σ and U are as previously shown.

Fig. 6.a and Fig 6.b shows an 'ideal' pattern and a model pattern. The figures given by Urlick are for 1 yard as reference distance, but have been converted to 1 meter reference distance in Fig. 6. To go from dB(yard) to dB(meter), we subtract 0.78 dB. The dB as given in this analysis are all with 1 meter as reference distance.



(a)

"Ideal" pattern for
target strength
ref 1 m



(b)

Target strength
pattern from model
ref 1 m

Figure 6 - TARGET STRENGTH

The active sonar equation is;

$$P = \frac{P_0 \cdot G_t \cdot \sigma \cdot G_r \cdot \lambda^2}{(4 \cdot \pi)^3 \cdot R^4} \quad \text{Watts} \quad (4.9)$$

P = power received

P_0 = power transmitted

G_t = gain transmitting, ref Eq. (4.1)

σ = target cross section, ref Eq. (4.8)

G_r = gain receiving, ref Eq. (4.1)

λ = wavelength in meters.

R = range to target in meters.

This may be rewritten into an expression of power received as a function of the variables of the different terms;

$$P = K \frac{\left| \frac{\sin(X_t \cdot \pi)}{X_t \cdot \pi} \right|^2 \cdot a^2 \cdot b^2 \cdot c^2 \cdot R^2 \left| \frac{\sin(X_r \cdot \pi)}{X_r \cdot \pi} \right|^2}{R^4 \cdot (a^2 \cdot \cos^2 \phi + b^2 \cdot \sin^2 \phi)} \quad (4.10)$$

K = the product of all the constants in the terms.

For more detailed discussion about gain, transmission loss and reflection (target cross section), see [1;110-111] and [6;29,94,263].

We can now calculate the minimum power level for detection by setting:

R_t = technical detection range

X_t = 0 degree

X_r = 0 degree

ϕ = 90 degrees

and we get

$$P_{\min} = K \frac{a^2 \cdot b^2 \cdot c^2 \cdot R_t^2 \cdot U}{R_t^4 \cdot (b^2)^2} \quad (4.11)$$

and by substituting for U

$$P_{\min} = K \frac{a^2 \cdot b^2 \cdot c^2 \cdot R_t^2 \cdot 3.08657}{R_t^4 \cdot (b^2)^2} \quad (4.12)$$

a, b and c are the dimension of the target used in the model.

We assume a 'standard' target, length 100 meters, beam 15 meters and draught 4 meters, i.e.

a = 100

b = 15

c = 4.

There will be a detection if $P/P_{\min} > 1$. Note that P/P_{\min} does not depend on K, into which radiated power and transducer gains have been included. The technical detection range R_t is an operationally meaningful surrogate

for these parameters. The ratio P/P_{\min} will be called the "intensity fraction".

3. Detection Rule

Any intensity-fraction calculated during a transmission which is greater than 1 is a detection. However, to improve the model at close ranges, the following modification has been made for gain variation due to relative bearing.

At close ranges, the relative bearing to target can alter considerably from bow to stern. Therefore, the intensity in the pulse will differ along the target. To average this intensity both for the radiated pulse and for the echo, the model calculates relative bearing to the target bow, center and stern, calculates the corresponding gain factor for each bearing, and finds the arithmetic mean of these gain factors. These two average gainfactors (transmitting and receiving) are then used in the calculation of echo intensity.

The model does not recognize a detection unless the tactical situation makes it possible to maintain contact with the target for some time. To be precise, the following conditions must be present;

- torpedo turn rate higher than bearing rate
- closing speed must be positive.
- target must have 2 knots doppler.

V. PRESENTATION OF DATA

A. STOCHASTIC ELEMENTS

In the previous description of the model, the following input values are stochastic;

- error in target speed
- error in target course
- error in target range
- initial torpedo course(not main course).

The primary stochastic effects on the torpedo performance are identified as errors in target speed and course, since these two variables are the only stochastic ones used in computing the torpedo main course. The first problem to be solved was then how to design the run series in order to reduce variance in result at the same time as keeping the result unbiased.

It was found that instead of using a complete randomized design (random variates); we could deterministically section the probability range 0.0 - 1.0 for the two important random variables, using the inverse probability transformation to get variates, and then run the number of runs required to cover all combinations of variates.

Some preliminary simulation runs were done in three

versions; complete randomized and independent; with antithetic reduction technique (sectioning); and the previously described procedure. The number of runs needed in order to keep the variance low for the result was considerably higher for the first two versions. Accordingly, we selected the previously described procedure. It was found that a series of 150 runs was sufficient in order to give a reasonable accuracy in detection probability and at the same time keeping the total CPU time for a series of runs acceptably low. The 150 run series was established by dividing the range of probability of target speed errors into 15 equally spaced sections; and the range of probability of target course errors into 10 equally spaced sections. Each section boundary point was by inverse probability transformation converted into a variate. Bearing in mind that speed errors are normally distributed and course errors are uniformly distributed, all combinations of target data error are plotted in Fig. 7.



Figure 7 - DISTRIBUTION OF ERROR IN TARGET DATA

B. TYPE OF PRINTOUT OF DATA AND RESULT

Each series of 150 runs produces a printout as shown. The heading of the printout gives the tactical situation and the torpedo parameters in the given run series. Also, the printout gives the sweep lane, which is the width of the lane where the torpedo has swept through by its sonar lobe. The coverage ratio gives an indication of the fraction of the lobe, which is covered twice; i.e. how much the lobe is being offset from its previous position by change in the torpedo course. The question of offsetting the sonar lobe, about which information is given in the printout, is discussed later in Ch. VI.

Ref. Fig. 8.

For each run, the following are output: target data, torpedo deflection angle, torpedo main course, target and torpedo grid position at end of run, duration of torpedo run and length of torpedo run.

After all runs in a series are completed, a summary is given.

Ref. Fig. 9.

The summary gives detection probability for a single detection, 2 successive detections, up to 5 successive detections. Also mean detection range, standard deviation of detection range, mean aspect, mean detection bearing relative to center bearing of sonar lobe and relative to main course are given.

Lastly, the detection range, the relative bearing to the center of the target and to the closest part of the target

TACTICAL SITUATION WHEN FIRING TORPEDO PARAMETERS
 RANGE ATTACK TARGET TARGET TORPEDO RANGE SPEED ANGLE ALTITUDE TURN DWEED COVERAGE
 3000. -90.0 270.0 19.0 150.0 40.0 30.0 20.0 18.0 1149.1 0.550
 SCAR MAIN LINE OFF-SET FROM CENTER BEARING 0.0 TIMES DEFLECTION ANGLE

ROW NO	EST OF TARGET COURSE	SPEED	RANGE	TORP DA	TORP COURSE	TORP COORD X	TORP COORD Y	TARGET COORD X	TARGET COORD Y	ROW STOP	TORP RUN
1	256.5	12.4	3345.	-17.5	342.5	14037.	15061.	13488.	15000.	163	3360.
NO DETECTION	MADE	DURING	THIS RUN								
2	256.5	14.2	2792.	-20.1	339.9	13825.	15199.	13394.	15000.	173	3570.
NO DETECTION	MADE	DURING	THIS RUN								
3	256.5	15.1	2980.	-21.5	338.5	13755.	15177.	13394.	15000.	178	3570.
NO DETECTION	MADE	DURING	THIS RUN								
4	256.5	15.8	2912.	-22.5	337.4	13695.	15149.	13394.	15000.	179	3570.
NO DETECTION	MADE	DURING	THIS RUN								
5	256.5	16.4	3232.	-23.5	336.5	13634.	15122.	13394.	15000.	178	3570.
NO DETECTION	MADE	DURING	THIS RUN								
6	256.5	17.0	3392.	-24.4	335.6	13597.	15106.	13394.	15000.	179	3570.
7	256.5	17.5	2922.	-25.2	334.8	13450.	15259.	13299.	15000.	184	3760.
8	256.5	18.0	3438.	-25.9	334.1	13434.	15251.	13299.	15000.	189	3780.
9	256.5	18.5	3312.	-26.7	333.3	13366.	15218.	13299.	15000.	189	3780.
10	256.5	19.0	2931.	-27.5	332.5	13342.	15206.	13299.	15000.	189	3760.
11	256.5	19.6	2948.	-28.4	331.6	13269.	15167.	13299.	15000.	189	3780.
12	256.5	20.2	3394.	-29.4	330.6	13241.	15151.	13299.	15000.	189	3760.
13	256.5	20.9	2997.	-30.5	329.5	13154.	15101.	13299.	15000.	189	3780.
NO DETECTION	MADE	DURING	THIS RUN								
14	256.5	21.8	2918.	-32.1	327.9	12977.	15229.	13205.	15000.	199	3990.
NO DETECTION	MADE	DURING	THIS RUN								
15	256.5	23.0	3230.	-35.0	325.0	12913.	15119.	13205.	15000.	199	3990.
NO DETECTION	MADE	DURING	THIS RUN								
16	256.5	12.4	3430.	-17.7	342.3	14033.	15058.	13488.	15000.	163	3360.
NO DETECTION	MADE	DURING	THIS RUN								
17	256.5	14.2	3277.	-20.4	339.6	13816.	15195.	13394.	15000.	173	3570.
NO DETECTION	MADE	DURING	THIS RUN								
18	256.5	15.1	3354.	-21.8	338.2	13733.	15163.	13394.	15000.	173	3570.
NO DETECTION	MADE	DURING	THIS RUN								
19	256.5	15.8	3363.	-22.9	337.1	13670.	15137.	13394.	15000.	173	3570.
NO DETECTION	MADE	DURING	THIS RUN								
20	256.5	16.4	3282.	-23.8	336.2	13626.	15118.	13394.	15000.	178	3570.
21	256.5	17.0	2964.	-24.7	335.3	13581.	15098.	13394.	15000.	178	3570.
22	256.5	17.5	2793.	-25.5	334.5	13460.	15263.	13299.	15000.	189	3780.
23	256.5	18.0	2843.	-26.3	333.7	13380.	15229.	13299.	15000.	189	3780.
24	256.5	18.5	3260.	-27.1	332.9	13369.	15218.	13299.	15000.	189	3780.
25	256.5	19.0	2850.	-27.9	332.1	13325.	15196.	13299.	15000.	189	3760.
26	256.5	19.6	3338.	-28.3	331.2	13250.	15155.	13299.	15000.	189	3760.
27	256.5	20.2	2790.	-29.7	330.3	13198.	15127.	13299.	15000.	189	3780.
NO DETECTION	MADE	DURING	THIS RUN								
28	256.5	20.9	3384.	-30.9	329.1	13132.	15088.	13299.	15000.	189	3760.
NO DETECTION	MADE	DURING	THIS RUN								
29	256.5	21.8	2904.	-32.5	327.5	12953.	15212.	13205.	15000.	199	3990.
NO DETECTION	MADE	DURING	THIS RUN								

Figure 8 - EXAMPLE OF PRINTOUT HEADING

at detection (relative to present torpedo course), and the target aspect at detection are printed for each run for a single detection, 2 successive and 3 successive detections.

It also should be noted that it is possible to get a more detailed printout for each run by setting IPRINT = 0 in the main program (main program statement 035).

Ref. Appendix D. for example of detailed run printout.

From the printout data, it is possible to study different aspects of the detection process as well as to generate distributions of detection range, aspect, bearing etc.

VI. PARAMETRIC TORPEDO ANALYSIS

A. OBJECTIVES

The following approach was used:

The torpedo speed, the technical detection range and the lobe width were assumed to characterize a torpedo type. Within the type, it was possible to change the turn rate and the sweep angle.

A tactical situation was characterized by the attack angle, the target speed and the firing range.

The following questions were investigated:

- Can a torpedo be improved by offsetting its sonar lobe from the torpedo heading ?
Rephrased; it may be asked, is the sonar lobe searching in the right direction (most likely area) by pointing straight ahead along the torpedo course ?
- How do turn rate and sweep angle affect a torpedo's MOE ?
- How are the different torpedo types related to each other with regard to detection probability (MOE) ?

In the analysis, we started with a reasonable tactical situation; target speed 18 knots, range 3000 meters, technical detection range 750 meters. Initially, we changed the attack angles.

With regard to torpedoes, we started with three types of

torpedoes; 24 knots, 32 knots and 40 knots; all with 20 degree lobe width, 6 degree per second turn rate and 30 degree sweep angle.

B. OFFSETTING SONAR LOBE

The hypothesis was that when a torpedo is fired on a deflection angle course, the sonar lobe should be most effective if it scans across the bearing to the target. Or, the sonar lobe should be offset equal to deflection angle (DA). Ref. Fig. 10.

It was found that offsetting had a positive effect when attacking from ahead of target.

Ref. Fig. 11.a. and b.

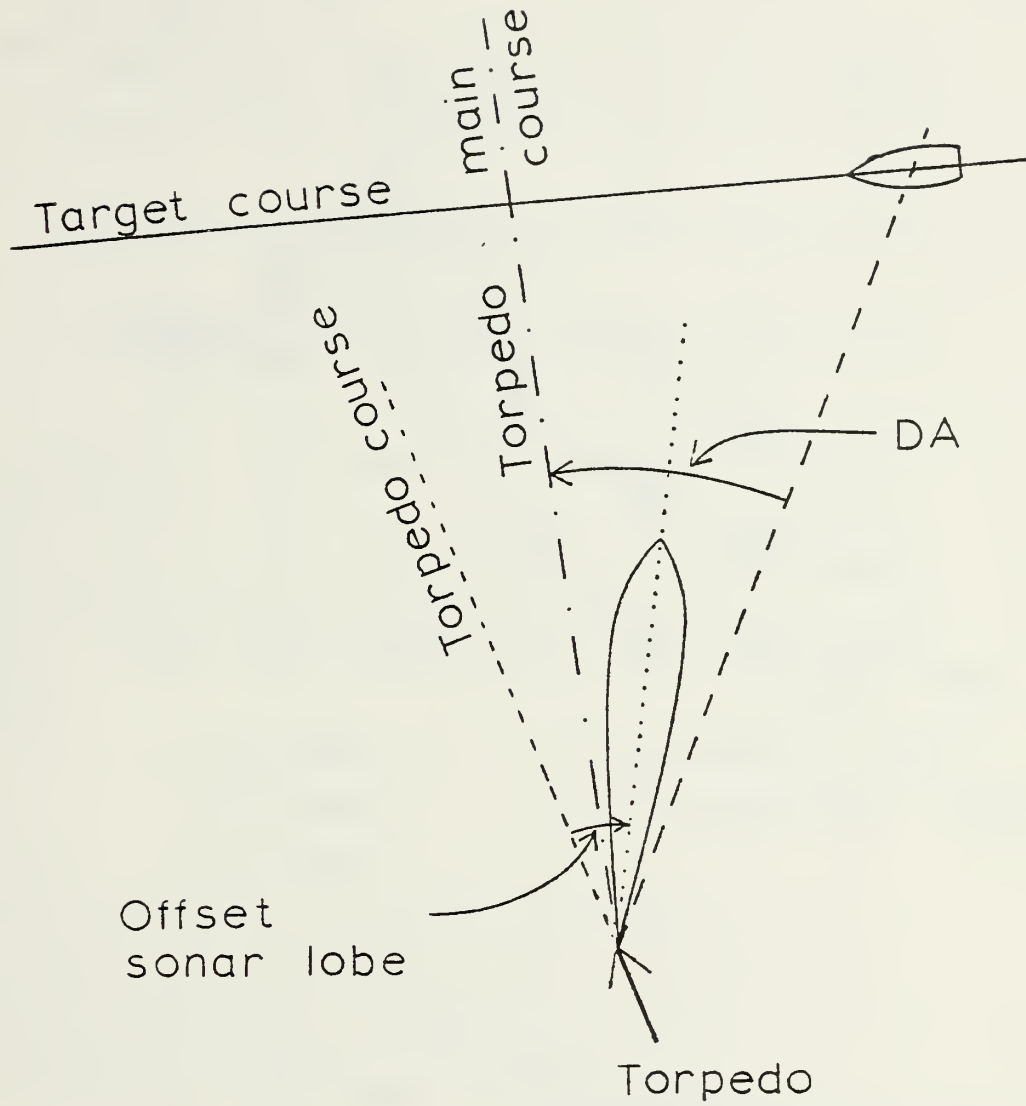
But from about 30 degree to about 110 degree attack angle the effect was negative. If more than 110 degree attack angle, there was no effect.

In analyzing the fraction of offsetting, we analyzed the case of 30 degree and 60 degree attack angle. There seemed to be no effect from 0.0 to 0.5 x DA; if more than 0.5 x DA there was a decreasing efficiency.

This was found for 2 types of torpedoes (32 and 40 knots; 20 degree lobe width) at 2 different sets of turn rates and sweep angles.

This conclusion applies for both single detection and multiple successive detections; however, the magnitude of the effect is changing as we look on different number of successive detections. The conclusion was that there is

little to be gained by offsetting the sonar lobe, and the sonar lobe was therefore not offset in subsequent investigations.



DA - Deflection angle

Figure 10 - OFFSET SONAR LOBE

Tactical Situation

Range 3000 m

TA Speed 18 Knots

Det. range 750 m

Torpedo Parameters

Sweep angle 30°

Lobe width 20°

Turn rate 6°/s

First detection

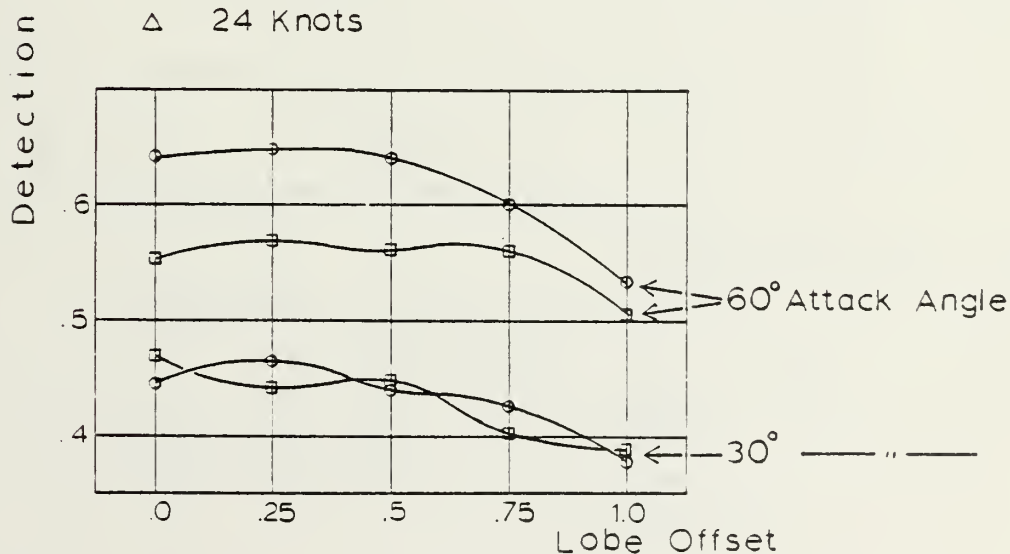
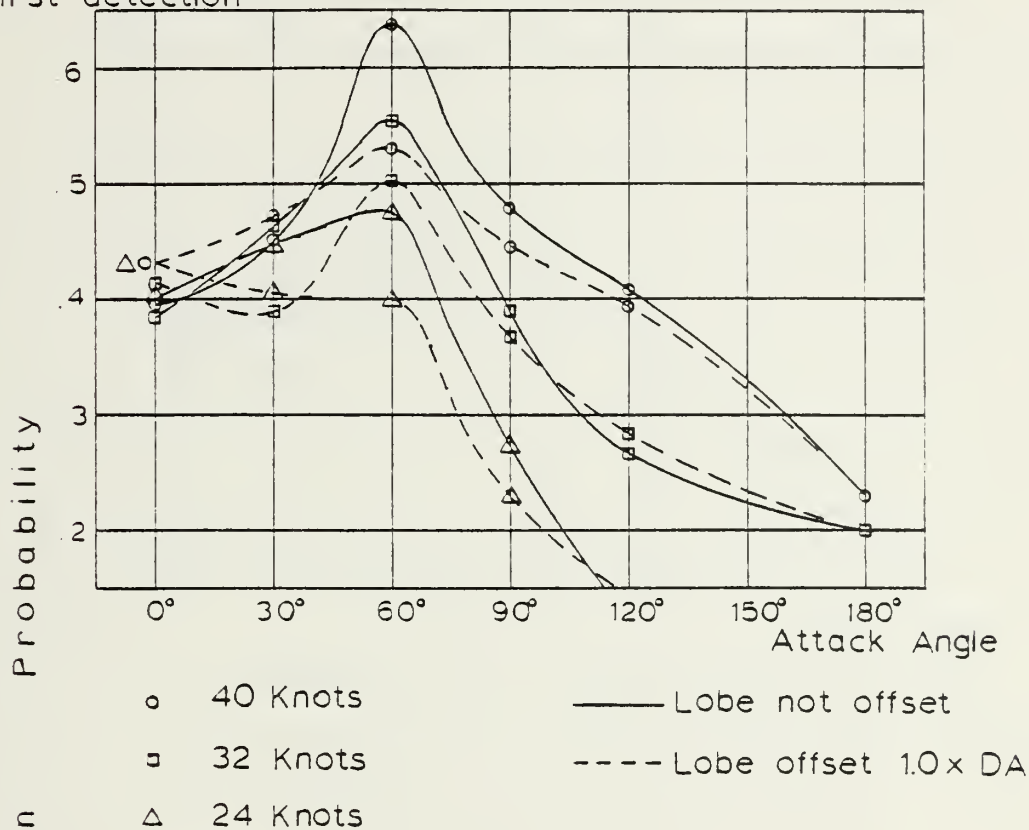


Figure 11 - EFFECT OF OFFSETTING SONAR LOBE

Tactical Situation

Range 3000 m
TA Speed 18 Knots
Det range 750 m

Torpedo Parameters

Sweep angle 30°
Lobe width 20°
Turn rate 6°/s

Two detections

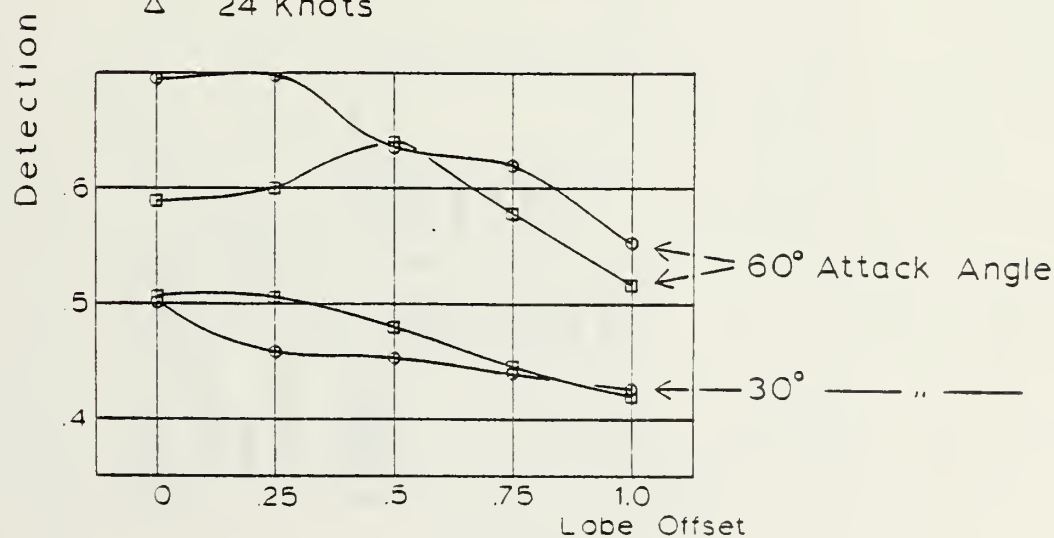
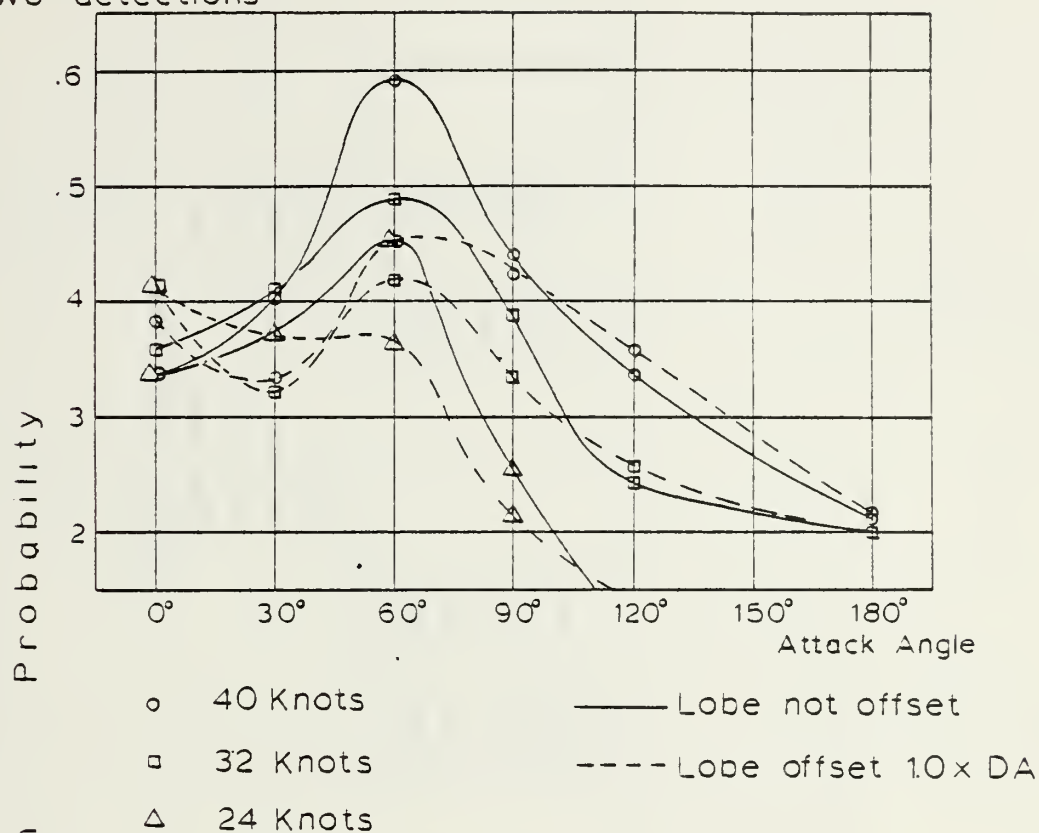


Figure 11.b. - EFFECT OF OFFSETTING SONAR LOBE

Tactical situation

Target speed 18 knots
Range 3000 m
Detection range 750 m

Torpedo parameters

Torpedo speed 24 knots
Sweep angle 30 degrees
Lobe width 20 degrees
Turn rate 6 deg/sec

Attack angle	1 detection		2 detections		3 detections		Offset lobe x DA
	0.0	1.0	0.0	1.0	0.0	1.0	
0	.4000	.4333	.3303	.4067	.3133	.3400	
30	.4467	.4067	.3733	.3667	.3200	.3133	
60	.4733	.4000	.4533	.3667	.4267	.3333	
90	.2733	.2267	.2533	.2133	.2400	.1867	
120	.1200	.1467	.1133	.1467	.1133	.1200	
180	.0000		.0000		.0000		

Table I - VARIATION IN OFFSETTING SONAR LOBE

Tactical situation

Target speed 18 knots
Range 3000 m
Detection range 750 m

Torpedo parameters

Torpedo speed 32 knots
Sweep angle 30 degrees
Lobe width 20 degrees
Turn rate 6 deg/sec

Attack angle	1 detection			2 detections			3 detections			Offset lobe x DA
	0.0	0.25	0.5	0.0	0.25	0.5	0.0	0.25	0.5	0.75
0	.3867			.3600			.2800			
30	.4667	.4400	.4467	.4067	.4067	.3800	.3400	.3067	.2867	.2733
60	.5533	.5667	.5600	.4867	.5000	.5400	.4333	.4600	.4333	.4133
90	.3933			.3867			.3067			
120	.2667			.2400			.2133			
180	.2000			.2000			.2000			

Tactical situation

Torpedo parameters

Attack angle	1 detection			2 detections			3 detections			Offset lobe x DA
	1.0			1.0			1.0			
0	.4267			.4067			.2733			
30	.3867			.3200			.2733			
60	.5067			.4200			.3600			
90	.3667			.3267			.3000			
120	.2800			.2533			.2400			
180	.2000			.2000			.2000			

Table I.b. - VARIATION IN OFFSETTING SONAR LOBE

Tactical situation

Torpedo parameters

Target speed 18 knots
Range 3000 m
Detection range 750 m

Torpedo speed 40 knots
Sweep angle 30 degrees
Lobe width 20 degrees
Turn rate 6 deg/sec

Attack angle	1 detection		2 detections		3 detections		Offset lobe x DA
	0.0	0.25	0.5	0.75	0.0	0.25	0.5
0	.3933			.3333	.2533		0.75
30	.4467	.4667	.4400	.4267	.3533	.3200	.3067
60	.6400	.6467	.6400	.5867	.6000	.4733	.4200
90	.4733			.4400	.3933		
120	.4067			.3400	.2800		
180	.2267			.2133	.2000		

Tactical situation

Torpedo parameters

Attack angle	1 detection		2 detections		3 detections		Offset lobe x DA
	1.0		1.0		1.0		
0	.4333		.3800		.2733		
30	.3733		.3267		.2733		
60	.5333		.4533		.4067		
90	.4467		.4200		.3600		
120	.3933		.3600		.3333		
180	.2333		.2200		.2000		

Table I.c. - VARIATION IN OFFSETTING SONAR LOBE

C. EFFECT OF TURN RATE

The effect of turn rate was investigated in the range 3 to 21 degrees per second in steps of 3. For both types of torpedoes the model showed an increase in MOE as turn rate was increased. The MOE leveled off as turn rate was approaching 15 - 20 degrees per second.

The reason may be due to the 1 second transmission interval and the 20 degree lobe width, which indicates that the torpedo should be turned at a turn rate equal to lobe width divided by transmission interval for maximum MOE. However, as the number of successive detections required is increased, we get maximum MOE at lower turn rates.

Fig. 12 shows the change in MOE with turn rate for 30 and 60 degrees attack angles.

From Fig. 15 where different combinations of turn rates and sweep angles are plotted versus MOE, we see that the effect is negligible from about 60-80 degrees to 180 degrees attack angle.

A 6 degrees per second turn rate is compared with what may be termed an 'optimal' turn rate in Fig. 13. The 'optimal' turn rates were established by the general trend from Fig. 12 and Table II.a and II.b.

The following turn rates were identified as 'optimal';

- 15 degrees per second for the 32 knots torpedo
- 18 degrees per second for the 40 knots torpedo.

Tactical Situation

Range

3000 m

TA Speed

18 Knots

Det. range

750 m

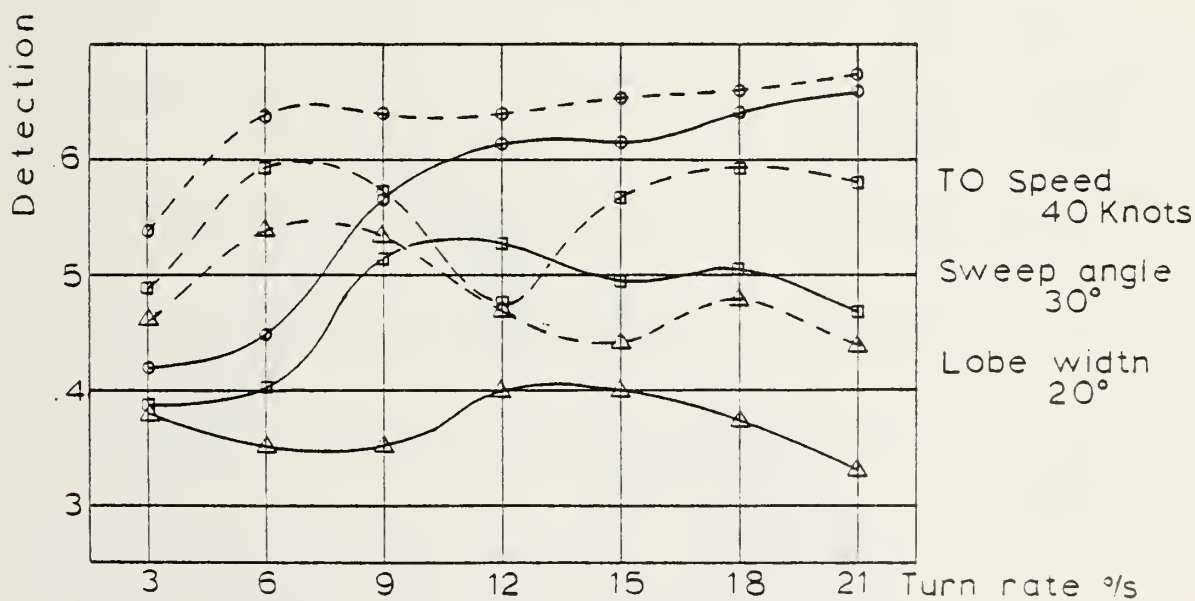
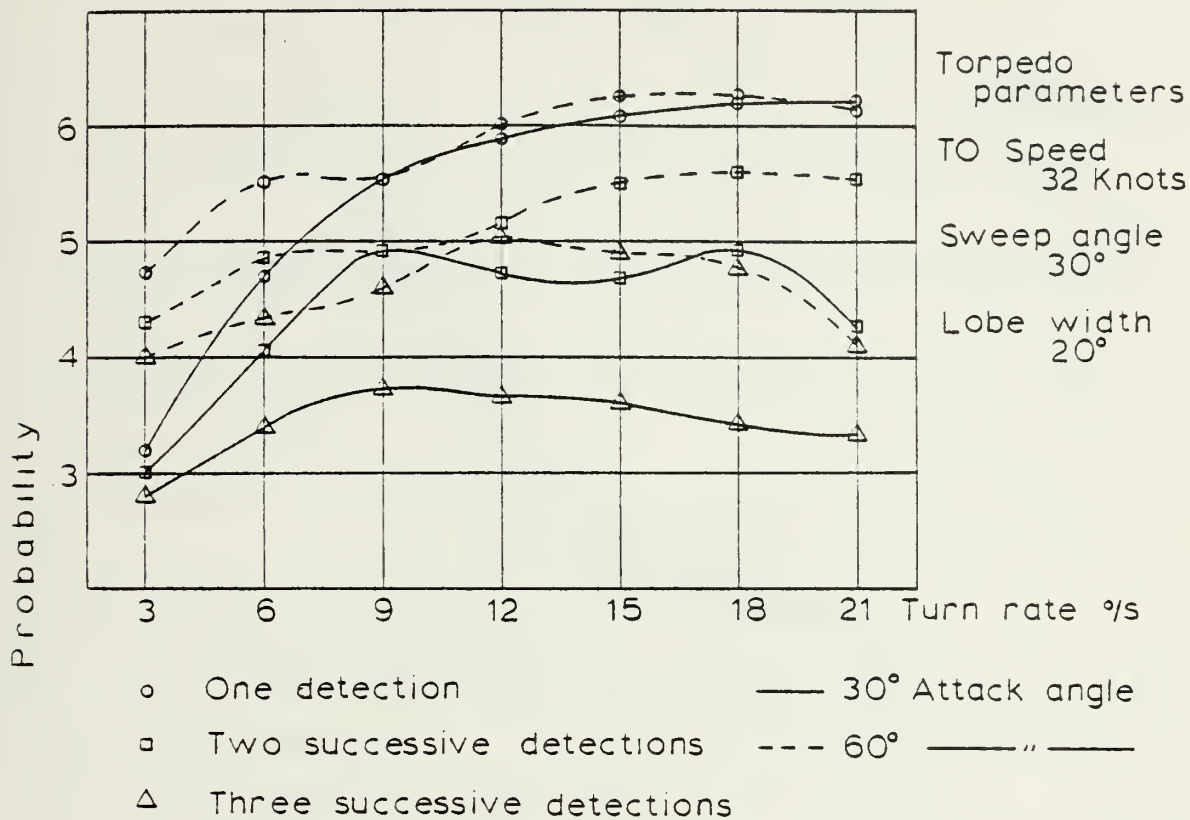


Figure 12 - EFFECT OF TURN RATE

Tactical Situation:

Range

3000 m

TA Speed

18 Knots

Det. range

750 m

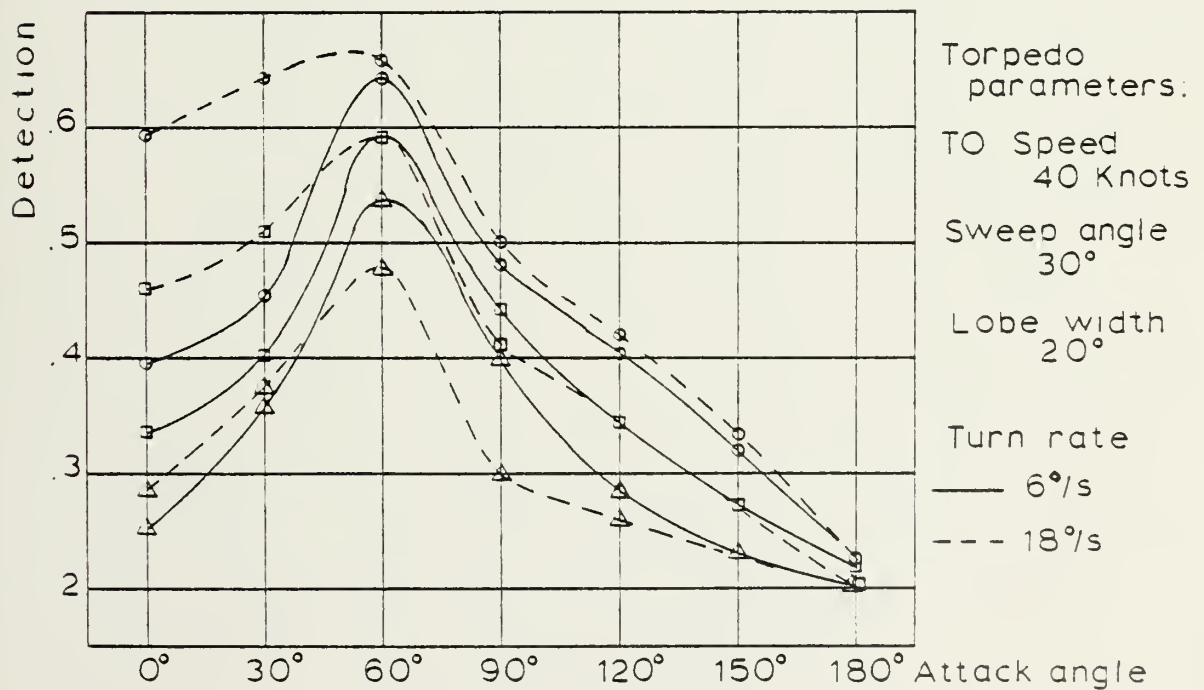
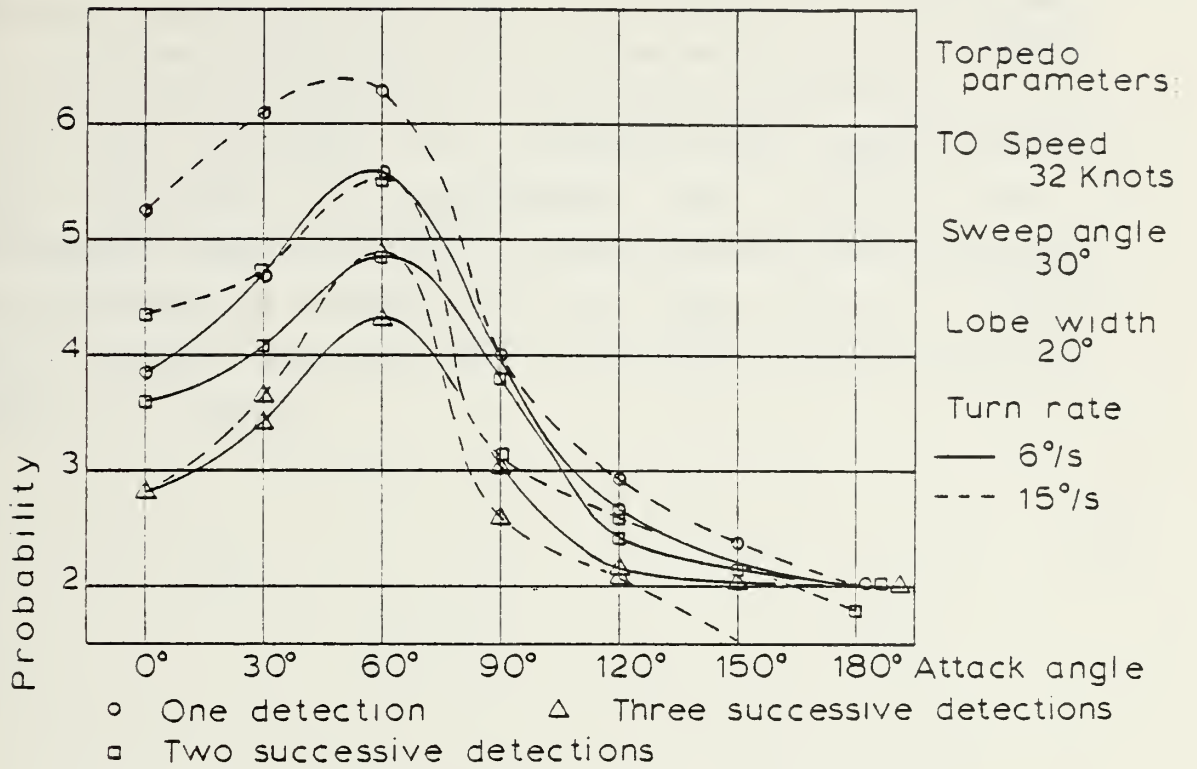


Figure 13 - COMPARISON OF TORPEDOES WITH DIFFERENT TURN RATES

We see here in Fig. 13 a considerable increase in MOE with increase in turn rate for attack angles less than 60 - 80 degrees for single detection; an consistent improvement for 2 successive detections in the same area; but no change or a slight detoriation for 3 successive detections.

It is quite obvious that a torpedo which requires only a single detection as requirement for attack has a considerably better MOE, and a considerably higher potential for improvement by changes in turn rate, than a torpedo which requires more successive detections for classifying a contact as a target.

Tactical situation

Target speed 18 knots
 Range 3000 m
 Detection range 750 m

Torpedo parameters

Torpedo speed 40 knots
 Sweep angle 30 degrees
 Lobe width 20 degrees

Attack angle	1 detection			2 detections			3 detections			Turn rate deg/sec
	3	6	9	3	6	9	3	6	9	
0		.3933			.3333			.2533		.2667
30	.4200	.4467	.5667	.3867	.4000	.5133	.3800	.3533	.3533	.4000
60	.5333	.6400	.6400	.4867	.5933	.5733	.4600	.5400	.5333	.4667
90		.6400			.4400			.3933		.3600
120		.4067			.3400			.2800		
180		.2267			.2133			.2000		

Tactical situation

Torpedo parameters

Attack angle	1 detection			2 detections			3 detections			Turn rate deg/sec
	12	15	18	12	15	18	12	15	18	
0	.5733		.5933	.4600		.4600	.2667		.2867	
30	.6133	.6133	.6400	.5267	.4933	.5067	.4000	.4000	.3733	.3300
60	.6400	.6533	.6600	.4667	.5667	.5933	.4667	.4400	.4800	.4400
90	.4733		.4933	.4400		.4067	.3600		.2933	
120			.4200			.3467			.2600	
180			.2267			.2000			.2000	

Table II.b. - VARIATION IN TORPEDO TURN RATE

D. EFFECT OF SWEEP ANGLE

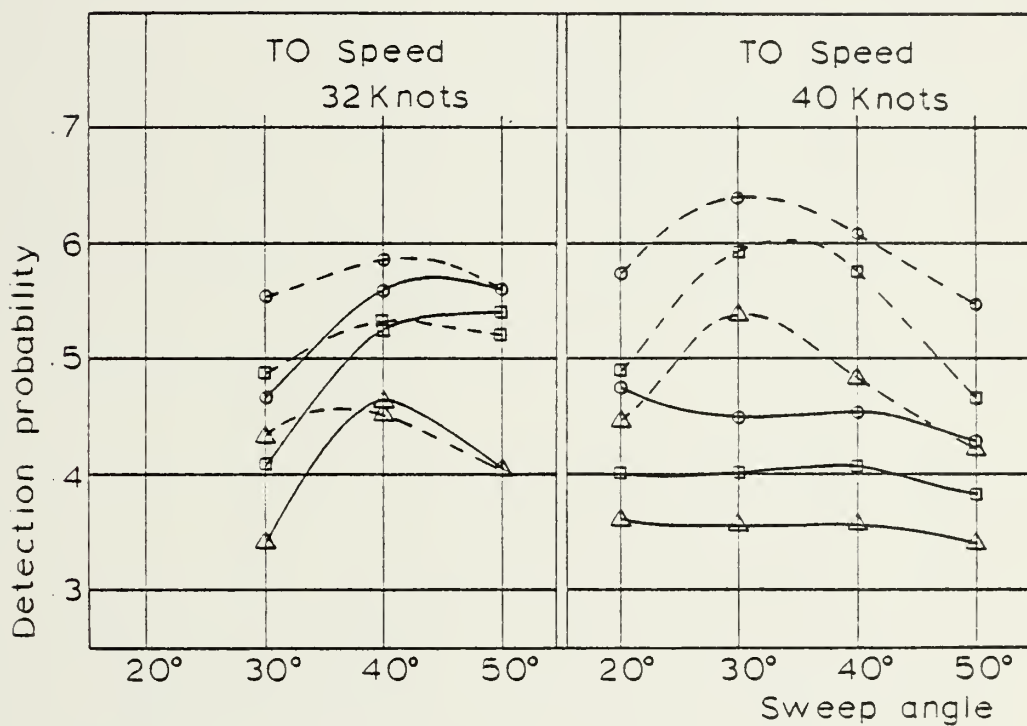
From preliminary simulation runs, it was found that from 90 degrees (inclusive) to 180 degrees attack angle the effect of the sweep angle was negligible. The analysis was therefore done from 20 to 50 degrees sweep angle only for 30 and 60 degrees attack angle for both the 32 and the 40 knots torpedo.

The result is shown in Fig. 14.

For the 32 knot torpedo we get an increase from 30 to 40 degrees for both attack angles. From 40 to 50 degrees, MOE either levels off or decrease slowly. As a conclusion, we established 40 degrees sweep angle as the 'optimal' value. For the 40 knot torpedo, the MOE was fairly steady over the whole range for 30 degrees attack angle. For 60 degrees attack angle, there was a peak at 30 degrees sweep angle, which indicated that 30 degrees was the optimal value.

The reason for the different sweep angles for the two torpedo types (Note; both have 6 degrees per second turn rate) may be due to the time it takes to reach the target. The shorter time, the less area on each side of the main course is needed to be covered in order to detect a target; i.e. a 40 knot torpedo needs only a 30 degree sweep angle, a 32 knot torpedo needs 40 degree sweep angle.

Tactical Situation:	Range	3000 m
	TA Speed	18 Knots
	Det. range	750 m
Torpedo Parameters:	Lobe width	20°
	Turn rate	6°/s



- One detection
- Two successive detections
- △ Three successive detections
- 30° Attack angle
- - - 60° " " —

Figure 14 - EFFECT OF SWEEP ANGLE

The reason why we get a peak and then a reduction in MOE as we increase sweep angle is supposedly due to a sharp decrease in speed along the main course as sweep angle is approaching 60 degrees.

As example, for a 40 knots torpedo the model gave 35 knots along main course for 50 degrees sweep angle as compared with 38.6 knots for 20 degrees sweep angle. For a slower torpedo, the effect on MOE may be considerable due to less speed advantage relative to the target.

Tactical situation

Target speed 18 knots
Range 3000 m
Detection range 750 m

Torpedo parameters

Torpedo speed 32 knots
Lobe width 20 degrees
Turn rate 6 deg/sec

Attack angle	1 detection			2 detections			3 detections			Sweep angle degree
	20	30	40	20	30	40	20	30	40	
0		.3867	.3933		.3600	.3267		.2800	.2600	
30		.4667	.5600		.4067	.5267		.3400	.4600	.4067
60		.5533	.5867		.4867	.5333		.4333	.4533	.4067
90		.3933	.3733		.3867	.3733		.3067	.3400	
120		.2667	.2800		.2400	.2667		.2133	.2333	
180		.2000	.2000		.2000	.2000		.2000	.1867	

Tactical situation

Target speed 18 knots
Range 3000 m
Detection range 750 m

Torpedo parameters

Torpedo speed 40 knots
Lobe width 20 degrees
Turn rate 6 deg/sec

Attack angle	1 detection			2 detections			3 detections			Sweep angle degree
	20	30	40	20	30	40	20	30	40	
0		.3933			.3333			.2533		
30	.4733	.4467	.4533	.4000	.4000	.4067	.3600	.3533	.3533	.3400
60	.5733	.6400	.6067	.5467	.5933	.5733	.4467	.5400	.4800	.4200
90		.4733			.4400			.3933		
120		.4067			.3400			.2800		
180		.2267			.2133			.2000		

Table III - VARIATION IN SWEEP ANGLE

E. EFFECT OF BOTH SWEEP ANGLE AND TURN RATE

In the previous discussion we changed either sweep angle or turn rate for both types of torpedo while we kept the other variables constant.

In plotting MOE for initial torpedo (32 knots) value, optimal value for sweep angle, optimal value for turn rate and the 'optimal' torpedo (having both the 'optimal' turn rate and sweep angle), we get Fig. 15.

Observe how the MOE changes as we apply the individual 'optimal' values, and the MOE obtained by applying both the 'optimal' values.

At this stage, no trials were made in order to further increase MOE by changing sweep angle or turn rate from these values.

One essential feature is that virtually none of the variables so far have had any effect on MOE for larger attack angles than 60-90 degrees.

The relative difference in MOE between the 32 and the 40 knots torpedo types is shown in Fig. 16. Both torpedoes are optimal in the sense that the best values for turn rate and sweep angle have been chosen for that specific speed.

Tactical Situation
 Range 3000 m
 TA Speed 18 Knots
 Det. range 750 m

Torpedo parameters
 TO Speed 32 Knots
 Lobe width 20°

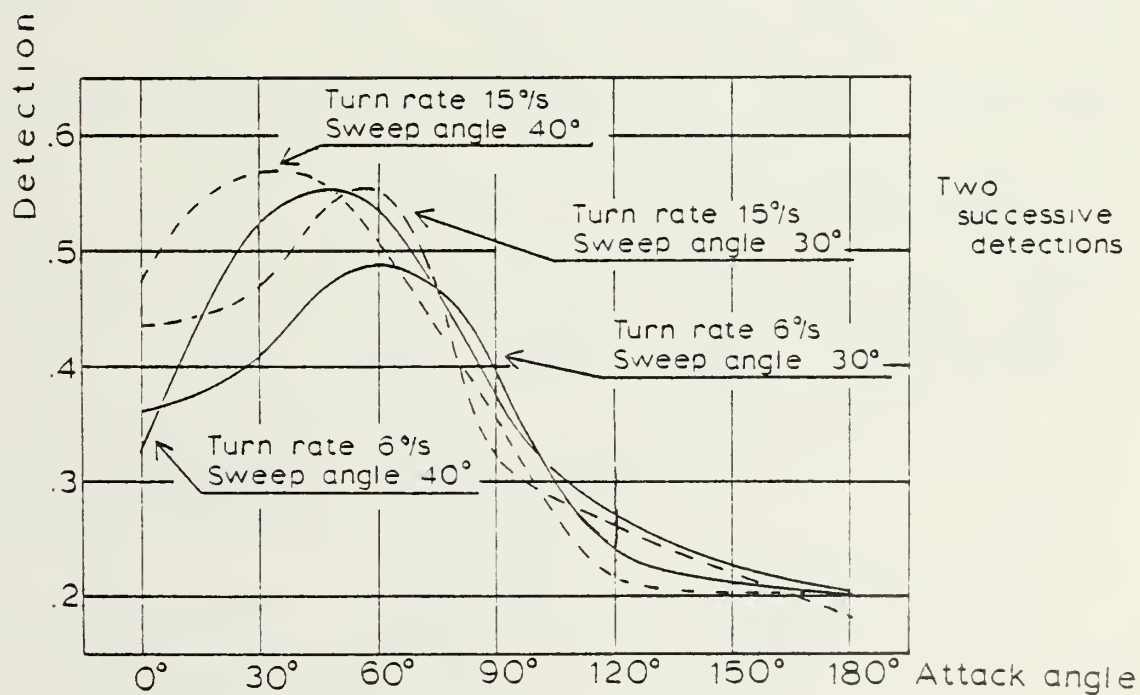
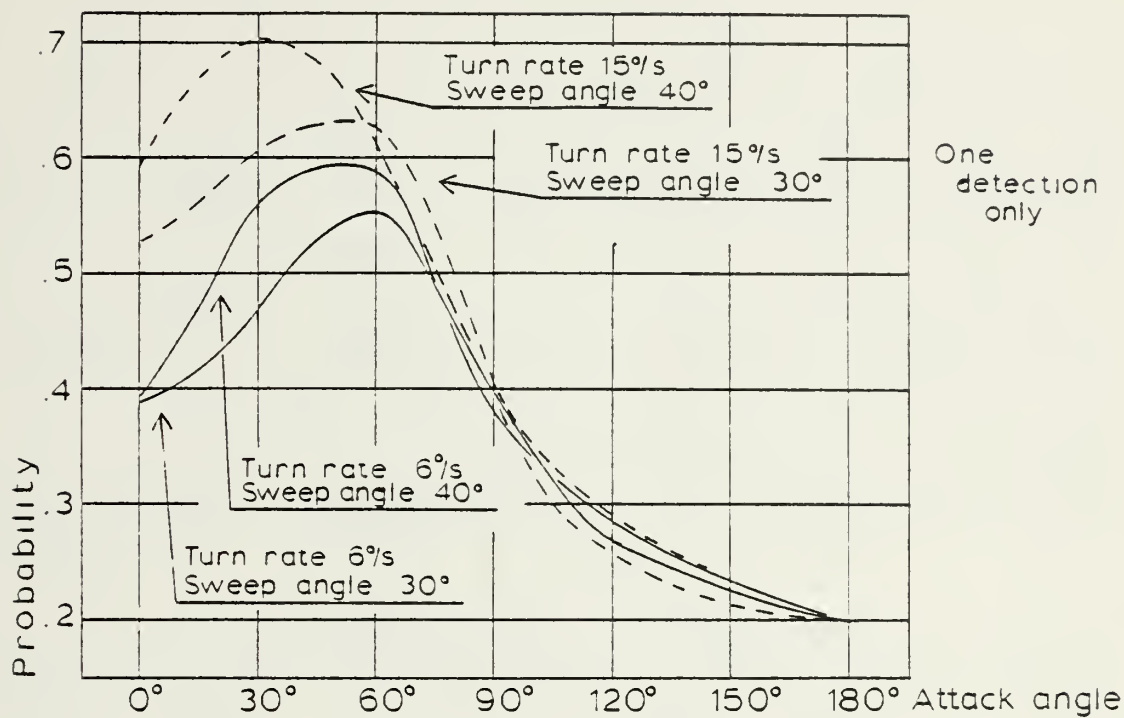


Figure 15 - COMPARISON OF DIFFERENT MODIFICATION OF A TORPEDO

Tactical Situation: Range 3000 m
 TA Speed 18 Knots
 Det. range 750 m

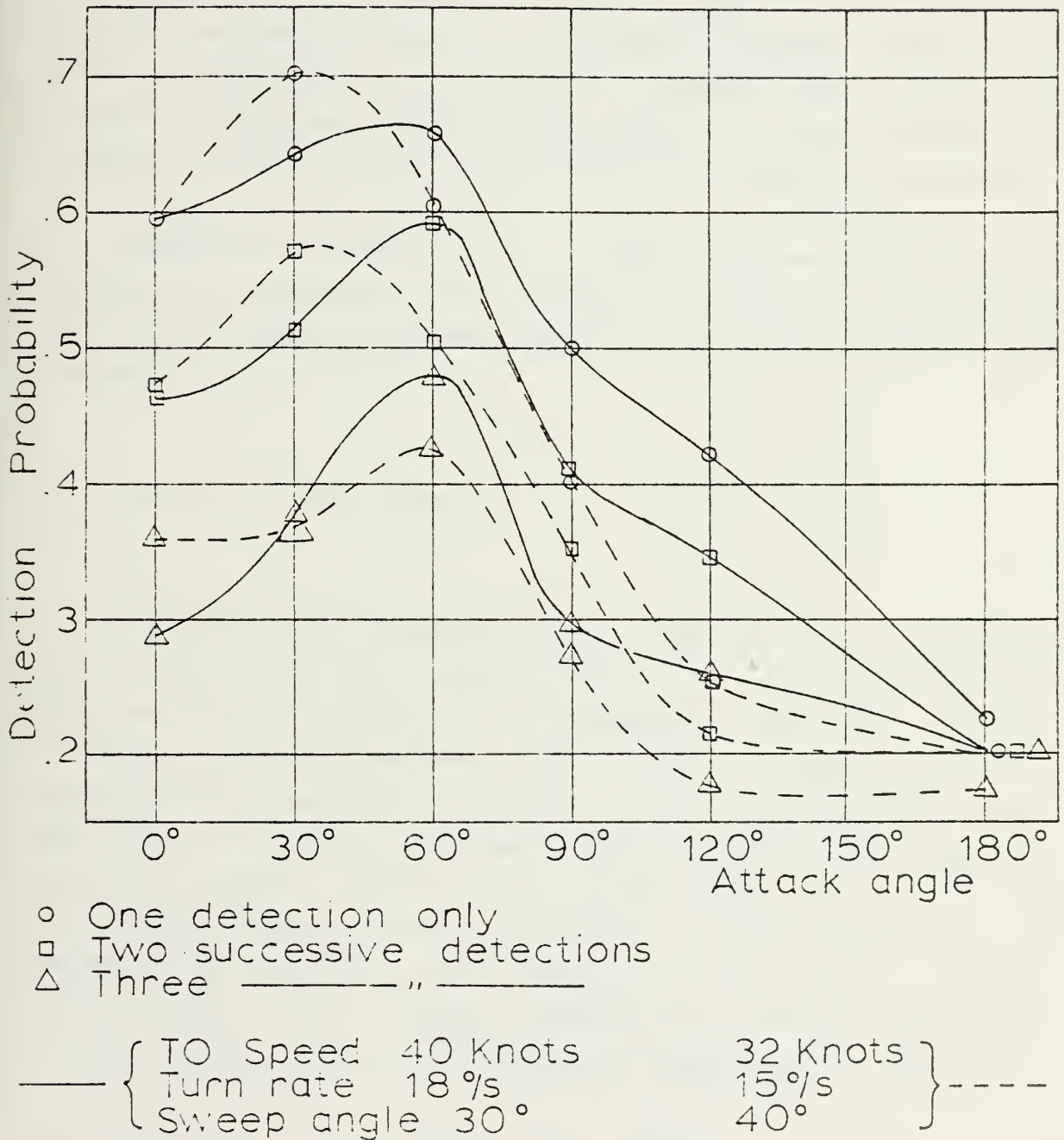


Figure 16 - COMPARISON OF TWO DIFFERENT TORPEDOES

It is obvious that the main differences are for large attack angles; more than 60-80 degrees. Especially if the acquisition requirement is one detection only, however, a 32 knots torpedo is slightly better up to 60 degrees attack angle. This improved MOE for the slower torpedo may be explained by a better balance between the time to the target and the total relative speed. A too high relative speed may prohibit the torpedo from getting the target within its sonar lobe before the target is passed.

Generally, however, the higher speed torpedo is superior, especially for larger attack angles (120 degrees and more); this can be explained by the shorter time to the target.

F. EFFECT OF LOBE WIDTH

The effect of changing lobe width while maintaining detection range is shown in Fig. 17. It should be noted that we initially started the simulation with an 'optimal' torpedo with 20 degrees lobe width. When we ran the simulation series for 10 degrees and 30 degrees lobe width, we did not change the other torpedo parameters in order to make the torpedo 'optimal' for the new lobe width. If we had carried through this optimization process, we might have expected an increase in the result for 10 and 30 degrees lobe width. The torpedo parameter in question would most likely be turn rate, see discussion previously on page 61.

The interesting points from Fig. 17 are;

- a 10 degrees lobe width torpedo with a one-detection-only acquisition requirement is as good

as a 20 degrees lobe width torpedo with a two-successive-detection requirement. This should indicate what we have to pay in additional power transmitted when acquisition requirement is high. Or, where to invest research resources; in transducer or in echo filtering.

- the equally shaped curves for increasing lobe width. However, we also observe an increasing difference in MOE between the curves as attack angle is decreasing.
- the importance of the correct balance between turn rate and lobe width for successive detections. We observe for a small aspect target how MOE decreases drastically when we reduce lobe width from 20 degrees to 10 degrees and maintain turn rate and require two successive detections.

Tactical Situation

TA Speed 18 knots
Det range 750 m
Range 3000 m

Torpedo Parameter

TO Speed 40 Knots
Sweep angle 30°
Turn rate 18 %s

△ 10° Lobe width
□ 20° " "
○ 30° " "

———— One detection only
----- Two successive detections

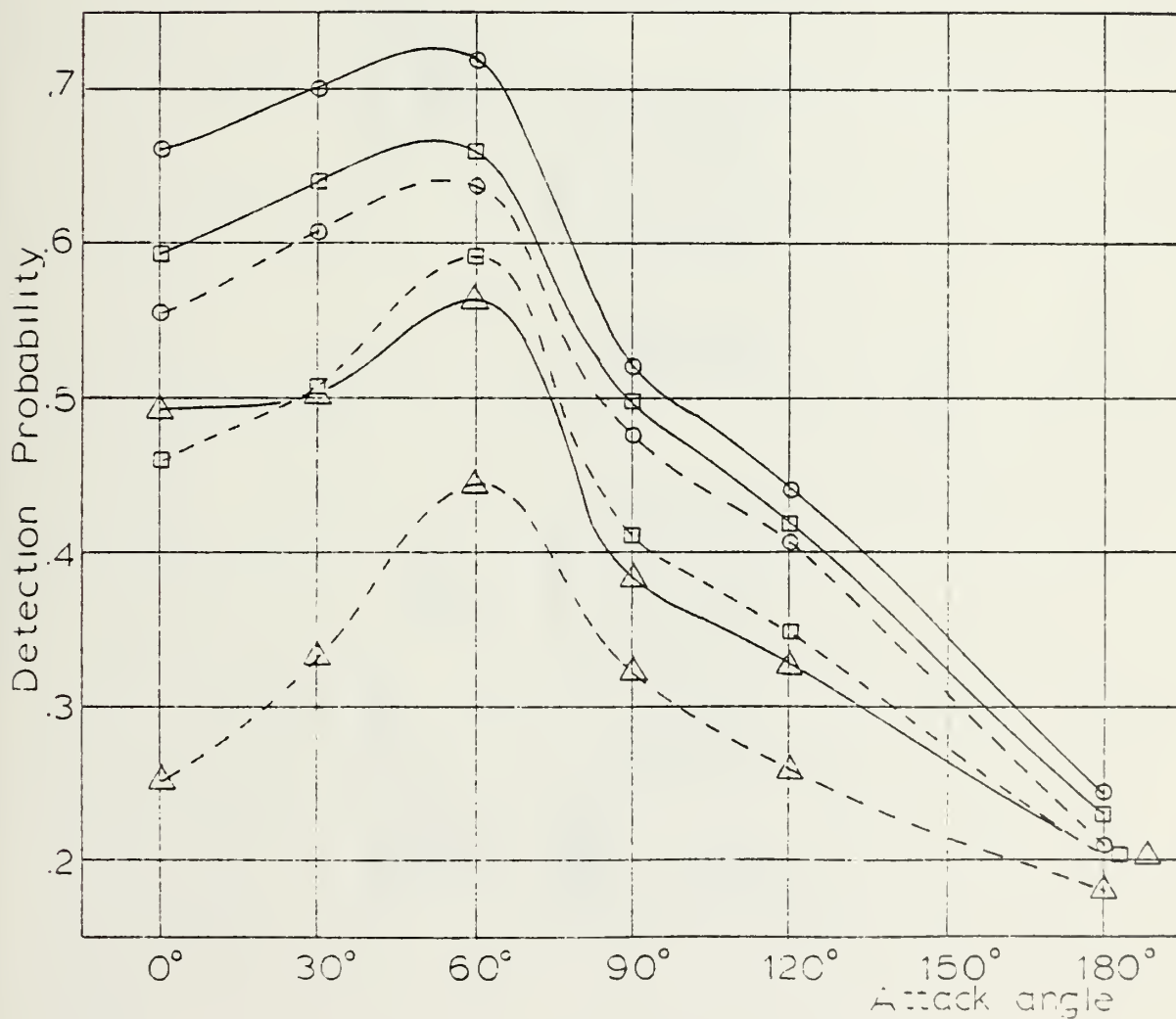


Figure 17 - EFFECT OF LOBE WIDTH

Table IV - VARIATION IN LOBE WIDTH

Tactical situation

Target speed 18 knots
Det. range 750 m
Range 3000 m

Torpedo parameters
Torpedo speed 40 knots
Sweep angle 30 degrees
Turn rate 18 deg/s

Attack angle	1 detection			2 detections			3 detections			Lobe width degrees
	10	20	30	10	20	30	10	20	30	
0	.4933	.5933	.6667				.1133	.2867	.4200	
30	.5000	.6400	.7000	.2167	.4600	.5533	.2333	.3733	.4800	
60	.5667	.6600	.7200	.4467	.5933	.6400	.3067	.4800	.5467	
90	.3800	.4933	.5133	.3200	.4067	.4733	.2267	.2933	.4000	
120	.3267	.4200	.4400	.2600	.3467	.4067	.1800	.2600	.3267	
180	.2000	.2267	.2400	.1800	.2000	.2067	.0867	.2000	.2000	

G. EFFECT OF DETECTION RANGE

The detection range is a function of the design of the active sonar in the torpedo as well as sonar condition at the time of the torpedo firing. The detection range as a function of the design of the active sonar is termed technical detection range. The detection range as a function of both the design and the sonar conditions is termed tactical detection range, or just detection range. In analyzing the detection probability as a function of detection range, we assumed optimal sonar conditions by equal technical detection range with detection range.

Detection range was varied in discrete steps: 375 - 750 - 1125 - 1500 meters.

Figs. 18.a. and b. indicate that detection probability is a linear function of the detection range up to a detection probability of 0.8 - 0.9 for one detection. From the model, it may be justifiable to approximate the detection probability as a linear function from 375 m to 1125 m detection range.

From the model and the given assumptions, there is little usefulness in a homing torpedo with less than 300 m detection range.

The same situation is shown in Figs. 19.a. and b. in another cut of the response surface. We see here how consistently the MOE has decreased over the whole range of attack angles when going from 1500 m to 375 m detection range.

Tactical Situation
 TA Speed 18 Knots
 Range 3000 m

Torpedo Parameters
 TO Speed 32 Knots
 Lobe width 20°
 Sweep angle 40°
 Turn rate $15^\circ/\text{s}$

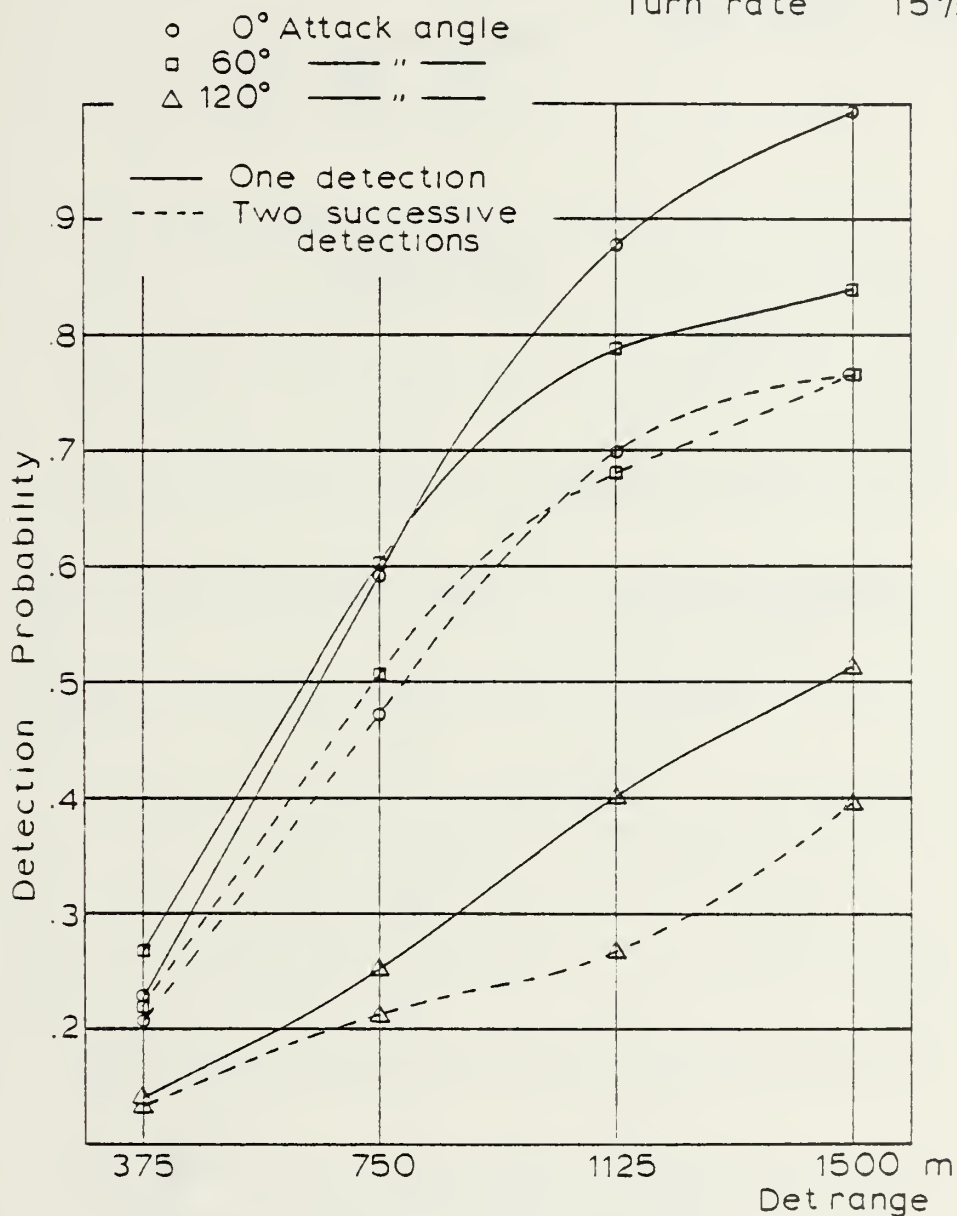


Figure 18 - EFFECT OF DETECTION RANGE

Tactical Situation:
 TA Speed 18 Knots
 Range 3000 m

Torpedo Parameters:
 TO Speed 40 Knots
 Lobe width 20°
 Sweep angle 30°
 Turn rate $18^\circ/\text{s}$

○ 0° Attack angle
 □ 60° " "
 △ 120° " "

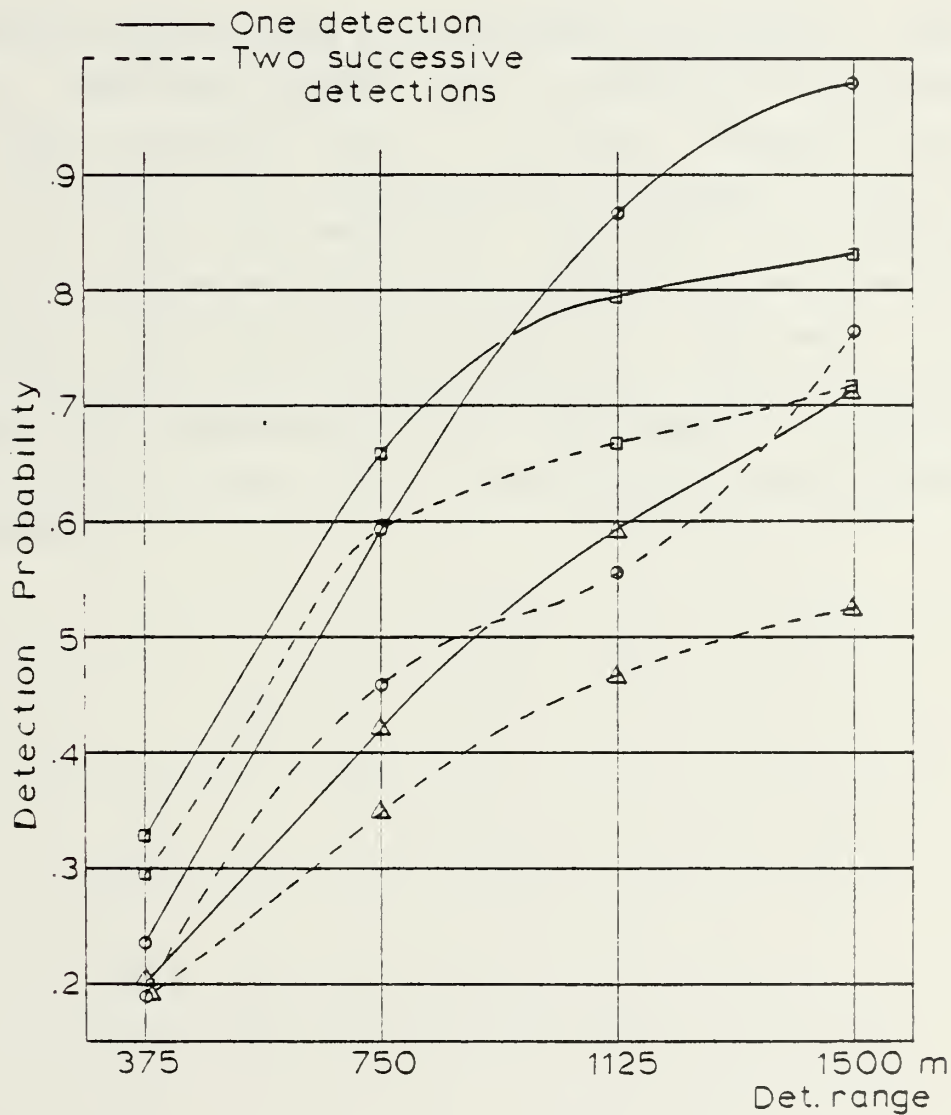


Figure 18.b. - EFFECT OF DETECTION RANGE

Otherwise the picture in Figs. 19.a. and b. is as in previous similar figures; a marked decrease in MOE with attack angles more than 60 - 90 degrees, and with the faster torpedo superior over most of the range. It should, however, be noted that for longer detection ranges we get maximum MOE at 0 degree attack angle for both torpedo types. This effect is reduced when we require two successive detections for acquisition.

We also experienced a considerable decrease in MOE for longer detection ranges when requiring two successive detections instead of one. It seems obvious that this reduction is due to a larger lateral movement at the extreme range. As noted previously, we increase the transmission interval (increase interval in order to allow time for echo to return) when the detection range is increased. Keeping the same turn rate, the sonar lobe will turn a larger angle between each transmission, which can have a deteriorating effect on MOE for more than a one-detection-only acquisition requirement.

Torpedo Parameters.

TO Speed 32 40 Knots
 Lobe width 20 20 °
 Sweep angle 40 30 °
 Turn rate 15 18 %/s

Tactical Situation.

TA Speed 18 Knots
 Range 3000 m

One detection

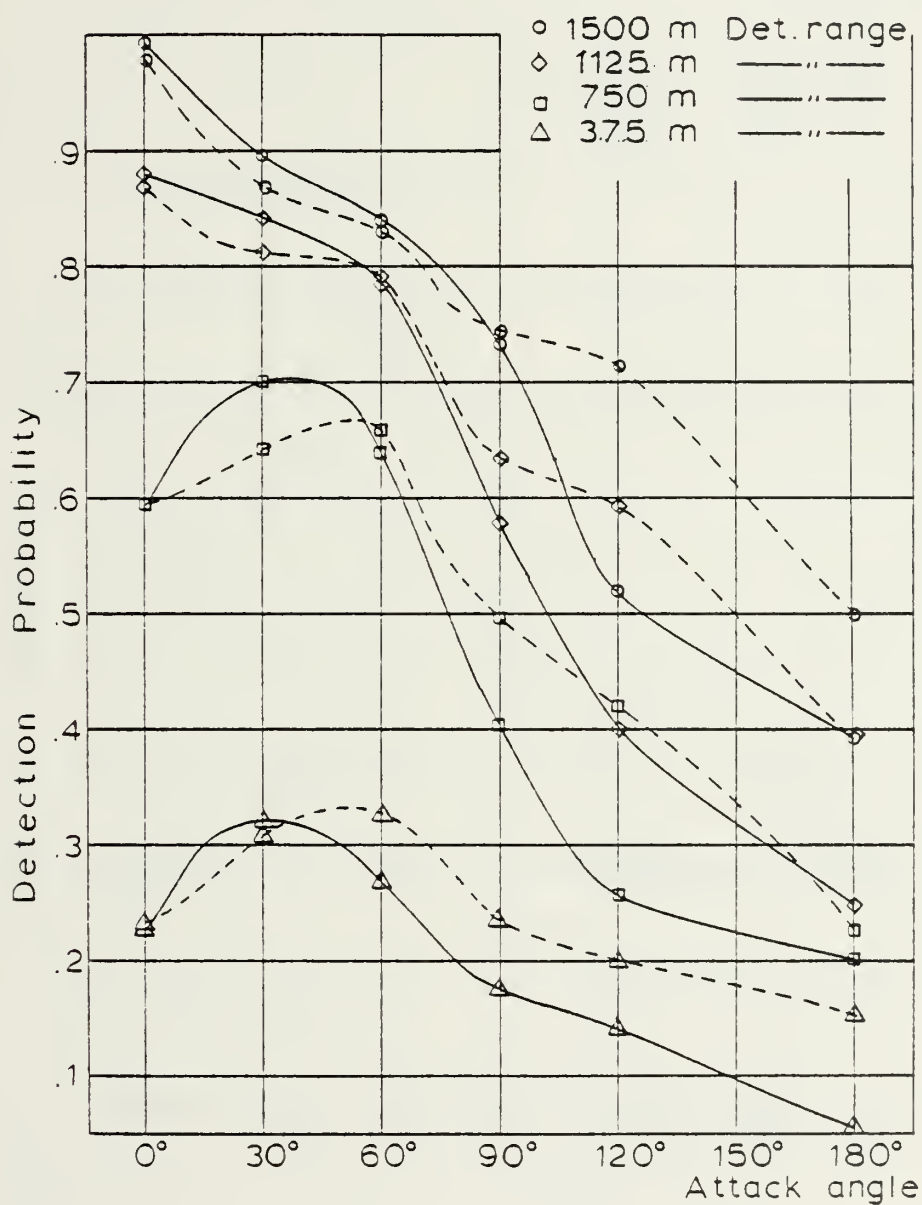


Figure 19 - COMPARISION OF TWO TORPEDOES WITH CHANGE IN
 DETECTION RANGE

Torpedo Parameters:

TO Speed 32 40 Knots
 Lobe width 20 20 °
 Sweep angle 40 30 °
 Turn rate 15 18 %s

Tactical Situation

TA Speed 18 Knots
 Range 3000 m

Two successive detections

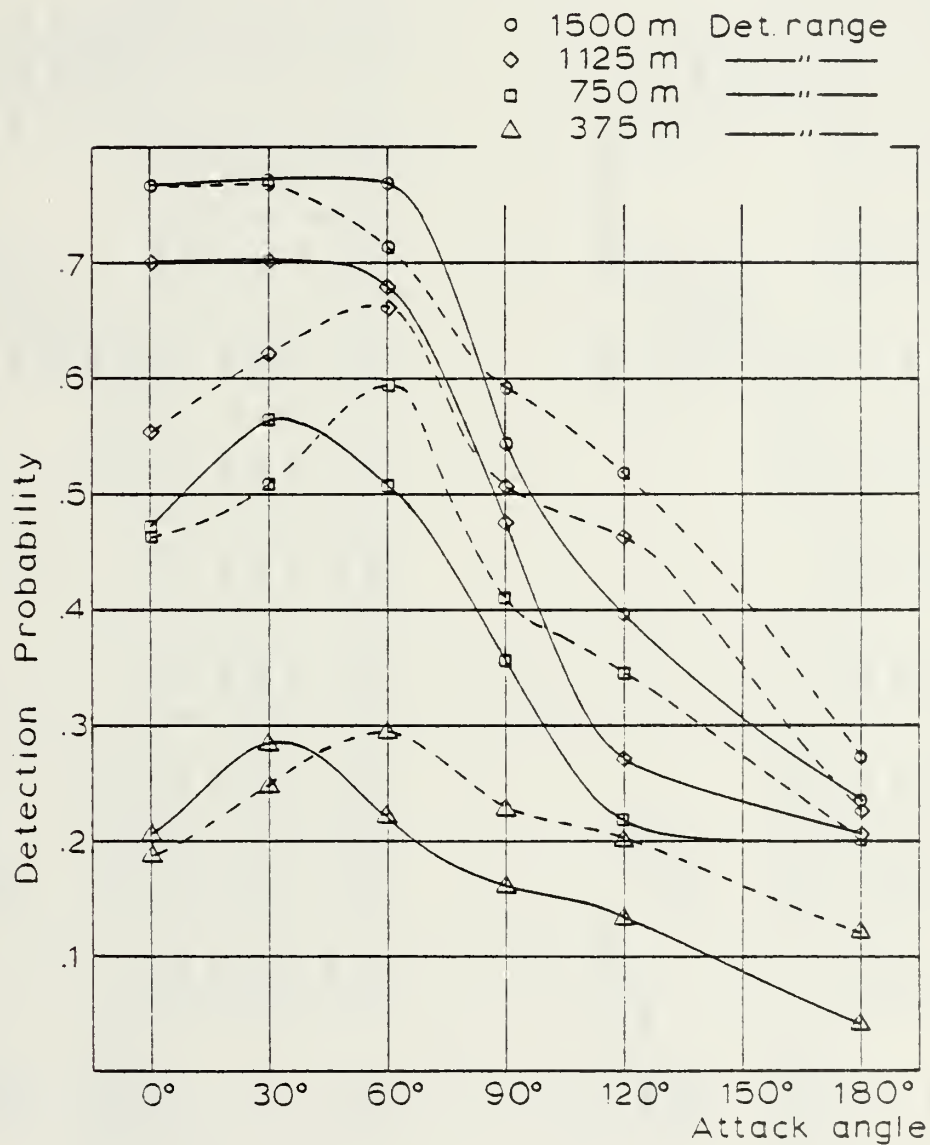


Figure 19.b. - COMPARISION OF TWO TORPEDOES
 WITH CHANGE IN DETECTION RANGE

Tactical situation

Torpedo parameters

Target speed 18 knots
Range 3000 m

Torpedo speed 32 knots
Sweep angle 40 degrees
Lobe width 20 degrees

Attack angle	Turn rate												Detection range m
	1 detection				2 detections				3 detections				
	375	750	1125	1500	375	750	1125	1500	375	750	1125	1500	
0	.2267	.5933	.8800	.9933	.2067	.4733	.7000	.7667	.1667	.3600	.4800	.5333	
30	.3200	.7000	.8333	.8933	.2867	.5667	.7000	.7667	.2600	.3667	.5267	.5933	
60	.2667	.6067	.7867	.8400	.2200	.5067	.6800	.7667	.1933	.4267	.5600	.6067	
90	.1733	.4000	.5800	.7333	.1600	.3533	.4733	.5467	.1400	.2733	.3667	.3667	
120	.1400	.2533	.4000	.5133	.1333	.2133	.2667	.3933	.1200	.1733	.1867	.2333	
180	.0533	.2000	.2467	.3933	.0400	.2000	.2067	.2333	.0267	.1733	.1933	.2000	

Tactical situation

Torpedo parameters

Target speed 18 knots
Range 3000 m

Torpedo speed 40 knots
Sweep angle 30 degrees
Lobe width 20 degrees

Attack angle	Turn rate												Detection range m
	1 detection				2 detections				3 detections				
	375	750	1125	1500	375	750	1125	1500	375	750	1125	1500	
0	.2333	.5933	.8667	.9800	.1867	.4600	.5533	.7667	.1267	.2867	.3533	.4000	
30	.3067	.6400	.8133	.8667	.2467	.5067	.6200	.7667	.1933	.3733	.4133	.4400	
60	.3267	.6600	.7933	.8333	.2933	.5933	.6667	.7133	.2200	.4800	.5000	.6267	
90	.2333	.4933	.6333	.7400	.2267	.4067	.5067	.5933	.1733	.2933	.3133	.3867	
120	.2000	.4200	.5933	.7133	.2000	.3467	.4667	.5267	.1733	.2600	.3133	.3333	
180	.1533	.2267	.3867	.5000	.1200	.2000	.2267	.2733	.0867	.2000	.2000	.2200	

Table V - VARIATION IN DETECTION RANGE

H. COMBINED EFFECT OF LOBE WIDTH AND DETECTION RANGE

The following approximate relationships exist between lobe width, detection range and sonar power:

$$P = \frac{P_0 \cdot G_t \cdot \sigma \cdot G_r \cdot \lambda^2}{(4\pi)^3 \cdot R^4} \quad \text{Watts} \quad (4.9)$$

where

$$G_t = G_r = (4\pi / w) \quad (6.1)$$

$$w = L^2$$

$$L = 2 \times \text{lobe width.}$$

Ref [1;49].

w is defined as solid angle. The given equation is valid for small lobe width only. For larger lobe width the exact relationship is;

$$w = 2\pi \cdot (1 - \cos l) \quad (6.2)$$

$$l = \text{lobe width.}$$

The approximate relationship is close enough up to 60 degrees lobe width.

By substituting the approximate relationship into Eq. 4.9, we get a reduction of L^4 in receiving echo due to change in lobe width,
or

$$(L \cdot R)^4 = \text{constant}, \quad (6.3)$$

which combine range and lobe width, and implies that detection range is inverse proportional to lobe width for constant power transmitted.

It is therefore possible to plot this function for constant power transmitted, and use this as a prediction of how MOE may change with change in these two torpedo parameters (lobe width and detection range).

This is done in Fig. 20; and indicated by the dashed line going through 20 degrees lobe width and 750 m detection range.

We then ran some simulation series in order to generate data points from the model. The data points gave the MOE, and by fitting curves we were able to get some indication of the relationship between the lobe width and the detection range as given by the model.

The application could be as follows;

For a given torpedo with lobe width 20 degrees and a detection range of 750 m, we ask the question, can MOE be increased without increasing power transmitted?

The dashed curve through the point (20 degrees, 750 m) is a constant power curve, and by following the curve we observe how MOE is changing.

From the figure, it is obvious that a narrower lobe and a longer detection range gives a better result. But we also observe the asymptotical feature of the curves. We reach a point where the constant power curve and the constant MOE curve are parallel.

However, it should be born in mind that the theoretical relationship between lobe width and detection range is an approximation which does not account for absorption-effect or surface-effect. This implies that the constant power

curve in real life will be lowered. Only a more detailed analysis can say how much.

Tactical Situation
 TA Speed 18 Knots
 Range 3000 m

Torpedo Parameter
 TO Speed 40 Knots
 Sweep angle 30 °
 Turn rate 18 %/s

One detection only

———— Constant detection probability
 - - - - - Constant power transmitted

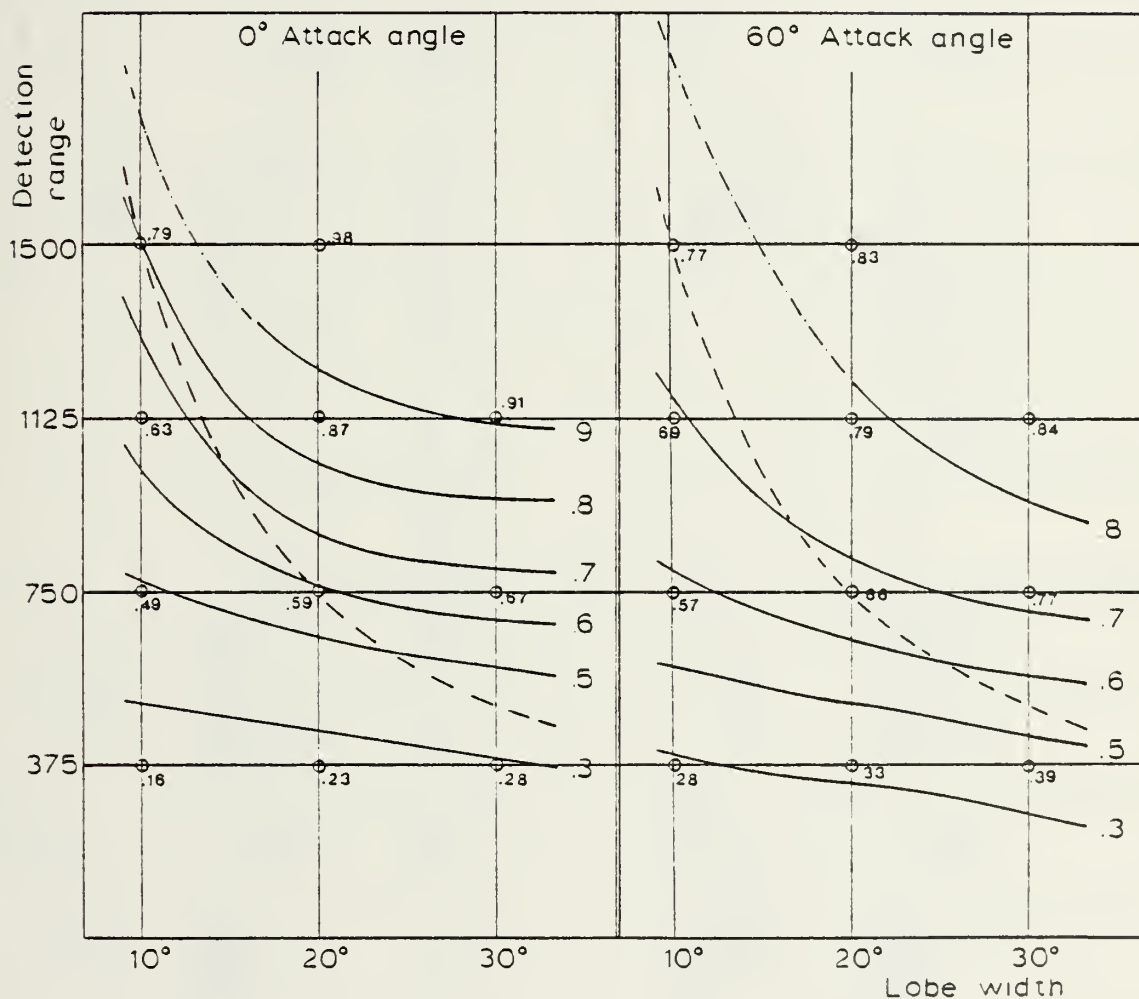


Figure 20 - VARIATION IN EFFECTIVENESS AS A FUNCTION OF LOBE WIDTH AND DETECTION RANGE

Tactical situation

Target speed
Range

18 knots
3000 m

Torpedo parameters

Torpedo speed
Sweep angle
Turn rate

40 knots
30 degrees
18 deg/s

Attack angle	1 detection			2 detections			3 detections			Detection range m
	375	750	1125	375	750	1125	375	750	1125	
0°	.1600	.4933	.6267	.1267	.2467	.3600	.1200	.1133	.1800	1500
60°	.2800	.5667	.6933	.1667	.4467	.5400	.0867	.3067	.3667	.1600 .3667
0°	.2333	.5933	.8667	.1867	.4600	.5533	.1267	.2867	.3533	.4000
60°	.3267	.6600	.7933	.2933	.5933	.6667	.2200	.4800	.5000	.6267

Tactical situation

Target speed
Range

18 knots
3000 m

Torpedo parameters

Torpedo speed
Sweep angle
Turn rate

40 knots
30 degrees
18 deg/s

Attack angle	1 detection			2 detections			3 detections			Detection range m
	375	750	1125	375	750	1125	375	750	1125	
0°	.2000	.6667	.9133	.2333	.5533	.6733	.1867	.4200	.4867	1500
60°	.3067	.7200	.8400	.3733	.6400	.7333	.3333	.5467	.6067	.30° lobe width

Table VI - VARIATION IN BOTH LOBE WIDTH AND DETECTION RANGE

I. EFFECT OF FIRING RANGE

The most important factor in achieving high detection probability is the difference between estimated target position and actual target position at the time when the torpedo is in position to detect. The effect on the detection probability is mainly due to the time the torpedo takes to reach within detection range of target and the speed/course errors in target data.

As we increased the firing range, we experienced as anticipated a degradation in MOE. This degradation was experienced for both the 32 and the 40 knots torpedo. The variation in firing ranges were at the following values: 1500 - 3000 - 5000 - 7000 meters.

Fig. 21.a. and b. shows consistently the importance of short firing ranges. This applies to both one detection and two successive detections.

Fig. 22.a. and b. shows an additional advantage with short firing ranges; a considerable improvement at firing with small aspect (attack angle), less than 30 degrees. Again this applies for both types of torpedoes.

Also, we get an indication that at short ranges, about 1500 meters, there is no significant difference in MOE of the two types of torpedoes up to an attack angle of 90 degrees.

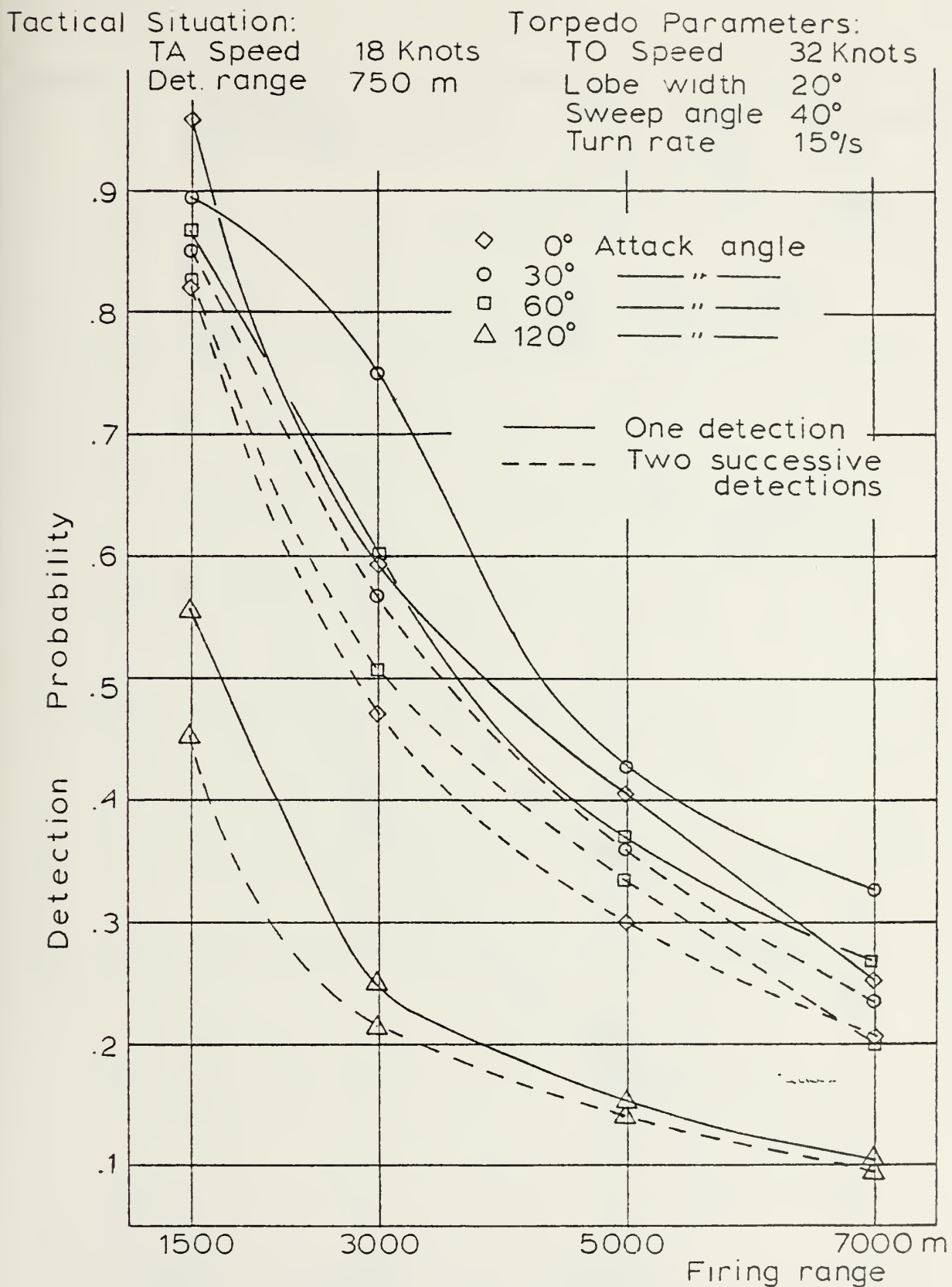


Figure 21 - EFFECT OF FIRING RANGE

Tactical Situation:

TA Speed 18 Knots

Det. range 750 m

Torpedo Parameters:

TO Speed 40 Knots

Lobe width 20°

Sweep angle 30°

Turn rate 18°/s

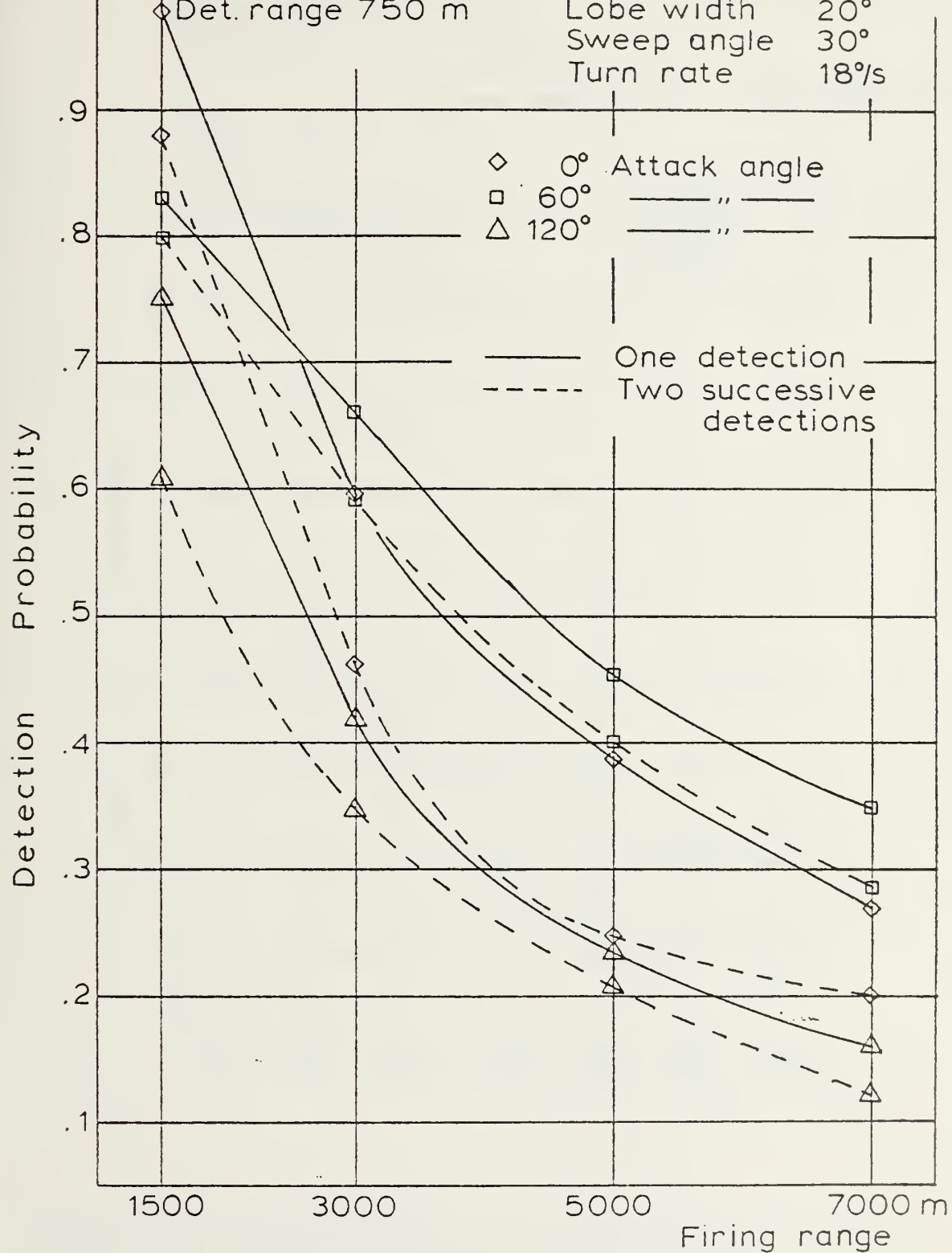


Figure 21.b. - EFFECT OF FIRING RANGE

Torpedo Parameters.

TO Speed 32 40 Knots
 Lobe width 20 20 °
 Sweep angle 40 30 °
 Turn rate 15 18 %/s

Tactical Situation

TA Speed 18 Knots
 Det range 750 m

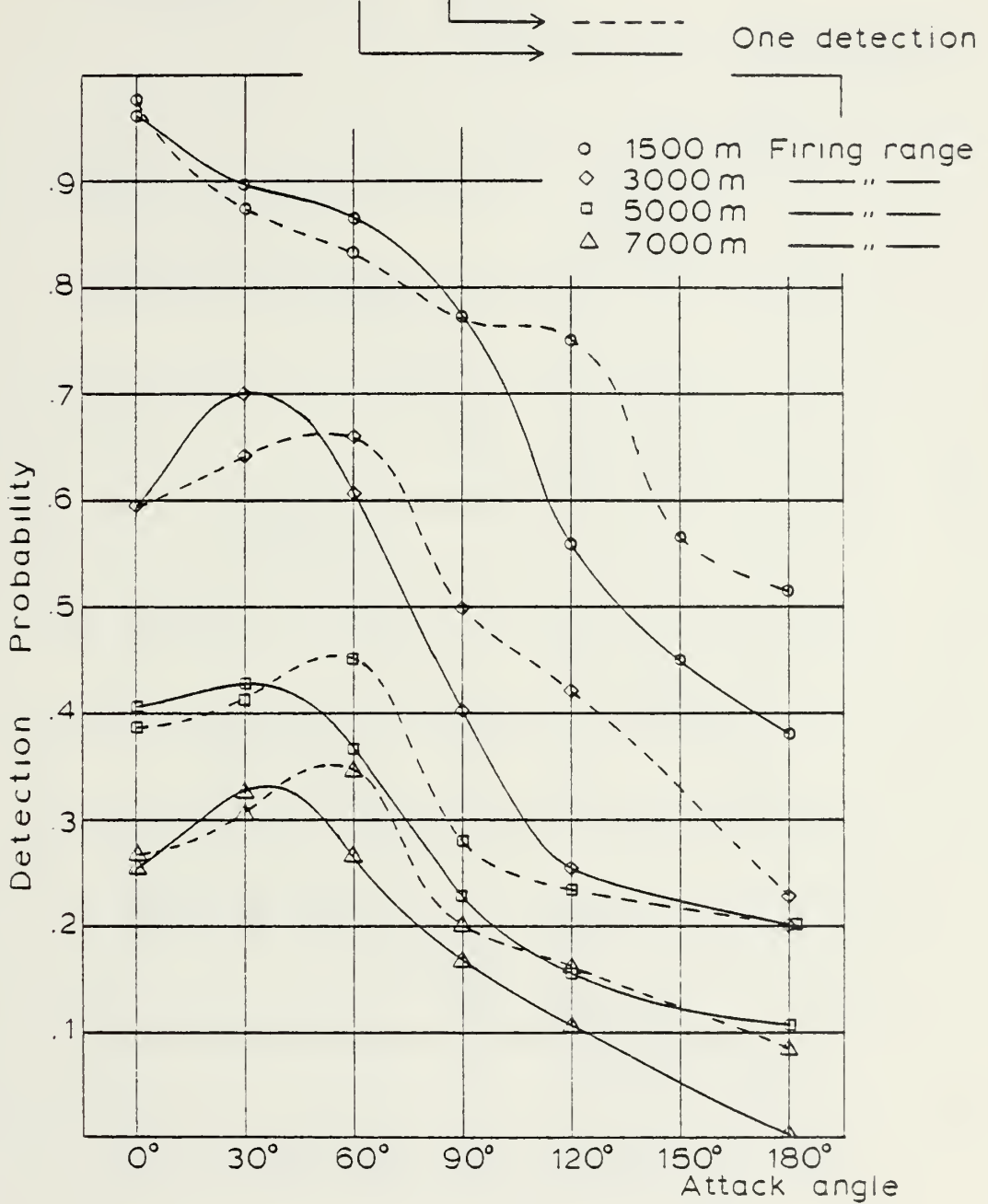


Figure 22 - COMPARISON OF TWO TORPEDOES WITH CHANGE IN FIRING RANGE

Torpedo Parameters

TO Speed	32	40 Knots
Lobe width	20	20 °
Sweep angle	40	30 °
Turn rate	15	18 °/s

Tactical Situation.

TA Speed	18 Knots
Det.range	750 m

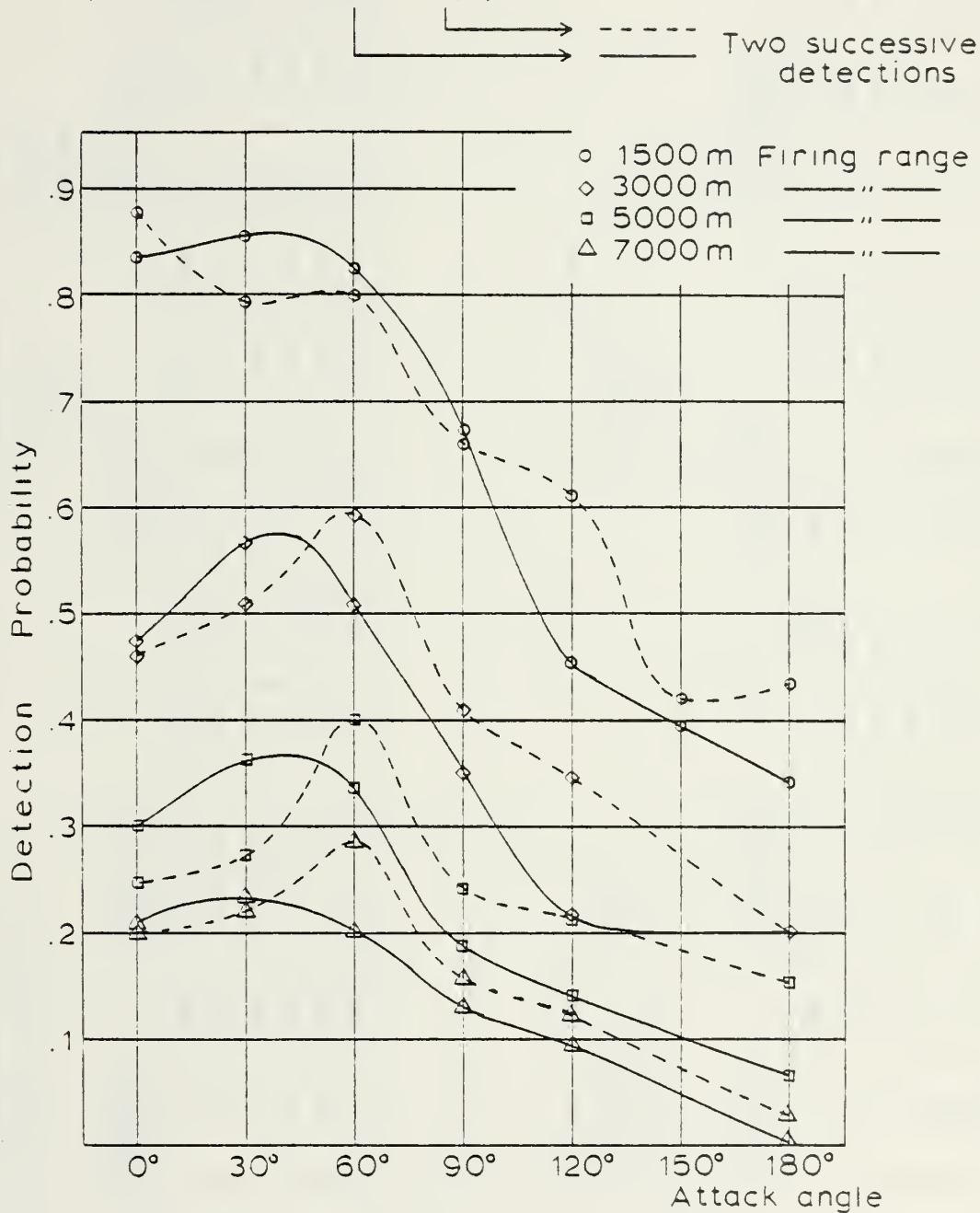


Figure 22.b. - COMPARISION OF TWO TORPEDOES WITH CHANGE IN FIRING RANGE

Tactical situation

Torpedo parameters

Target speed 18 knots
Detection range 750 m

Torpedo speed 32 knots
Sweep angle 40 degrees
Lobe width 20 degrees
Turn rate 15 deg/sec

Attack angle	1 detection			2 detections			3 detections			Range m
	1500	3000	5000	1500	3000	5000	1500	3000	5000	
0	.9600	.5933	.4067	.8333	.4733	.3000	.5600	.3600	.1733	.1000
30	.8933	.7000	.4267	.8533	.5667	.3600	.7533	.3667	.2533	.1800
60	.8667	.6067	.3667	.8267	.5067	.3333	.7267	.4267	.2400	.1867
90	.7733	.4000	.2267	.6733	.3533	.1867	.5333	.2730	.1600	.1200
120	.5600	.2533	.1533	.4533	.2133	.1400	.3467	.1733	.0867	.0533
180	.3800	.2000	.1067	.3400	.2000	.0667	.2667	.1733	.0133	.0000

Tactical situation

Torpedo parameters

Target speed 18 knots
Detection range 750 m

Torpedo speed 40 knots
Sweep angle 30 degrees
Lobe width 20 degrees
Turn rate 18 deg/sec

Attack angle	1 detection			2 detections			3 detections			Range m
	1500	3000	5000	1500	3000	5000	1500	3000	5000	
0	.9800	.5933	.3867	.8800	.4600	.2467	.5200	.2867	.1933	.1533
30	.8733	.6400	.4133	.7933	.5067	.2733	.6800	.3733	.2000	.1600
60	.8333	.6600	.4533	.8000	.5933	.4000	.7333	.4800	.3133	.2000
90	.7667	.4933	.2800	.6600	.4067	.2400	.6000	.2933	.1933	.1333
120	.7533	.4200	.2333	.6133	.3467	.2067	.5000	.2600	.1467	.1000
180	.5133	.2267	.2000	.4333	.2000	.1533	.2867	.2000	.0467	.0000

Table VII - VARIATION IN FIRING RANGE

J. EFFECT OF TARGET SPEED

Generally, we anticipated a degradation in MOE as the target speed was increased. And overall, this was confirmed.

The simulations were carried through at 12, 18, 24, 30 knots target speed.

However, fig. 23.a and b shows some interesting patterns regarding optimal attack angle for different target speeds. For a 32 knots torpedo, at 60 degrees attack angle, the torpedo is equally good for any type of target speed for one detection only. For two successive detections, the torpedo is equally good between 30 and 90 degrees for 12 and 18 knots target. A 24 knots target gives a consistently lower MOE over the whole range of attack angles, and the 2 simulation runs with a 30 knots target confirmed that trend for the 32 knots torpedo.

We may form the conclusion that for one detection only 60 degrees attack angle is an optimal attack angle for the range of target speeds. For two successive detections, 30 to 90 degrees attack angle gives equally good MOE between target speed of 12 and 18 knots.

One interesting point is that it seems that if the target speed is less than 0.4 of the torpedo speed the optimal attack angle shifts forward to 0 degree. This also applies to two successive detections.

Tactical Situation:
 Range 3000 m
 Det.range 750 m

Torpedo Parameters:
 TO Speed 32 Knots
 Lobe width 20°
 Sweep angle 40°
 Turn rate 15 %s

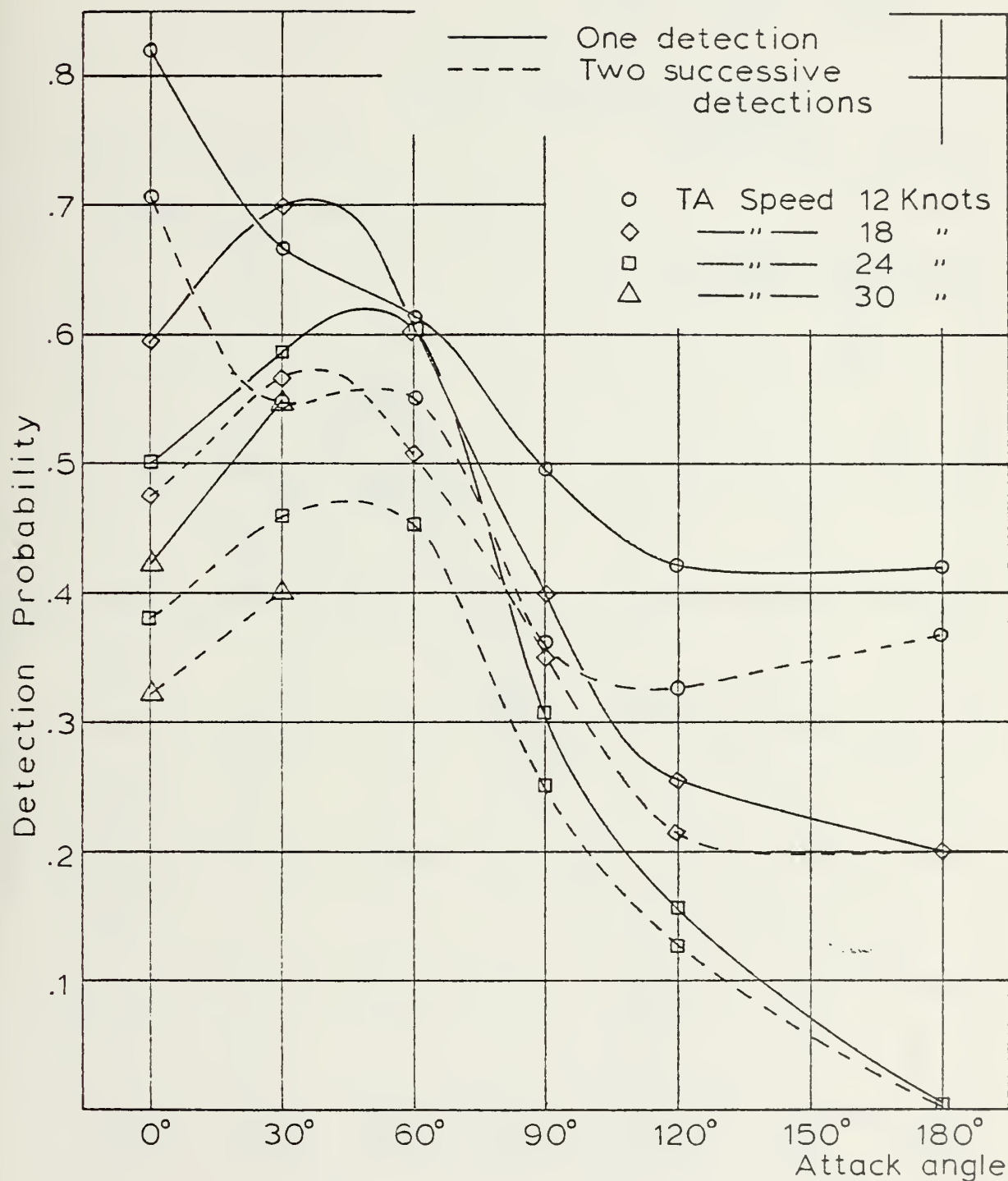


Figure 23 - EFFECT OF TARGET SPEED

Tactical Situation:
 Range 3000 m
 Det. range 750 m

Torpedo Parameters:
 TO Speed 40 Knots
 Lobe width 20°
 Sweep angle 30°
 Turn rate 18°/s

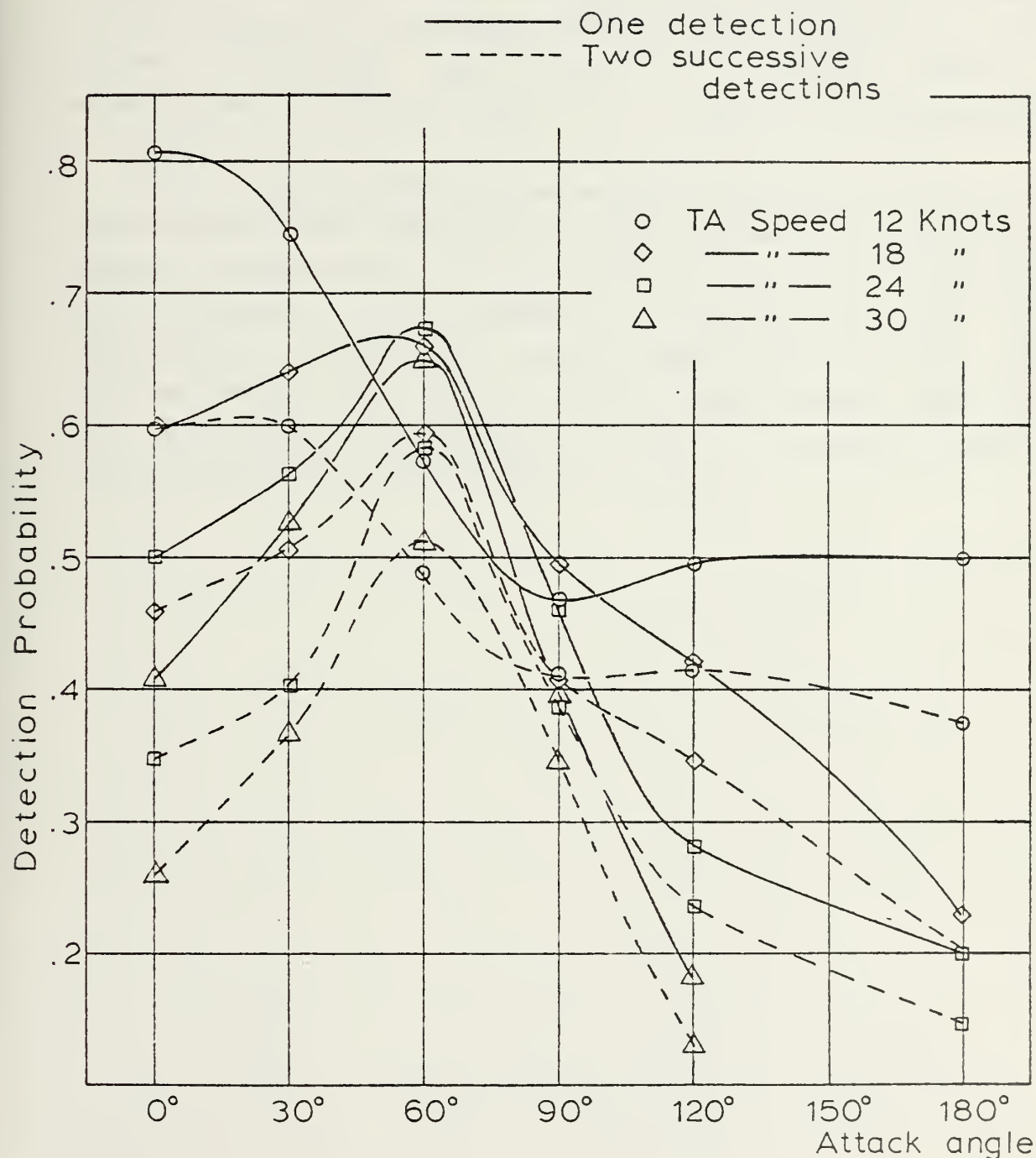


Figure 23.b. - EFFECT OF TARGET SPEED

For a 40 knot torpedo, in addition to the point of optimal attack angle at 0 degree for slow target speeds, we also experienced a relatively low MOE for slow targets in the range 45 to 105 degrees attack angle, compared to fast targets. But as a compensation, MOE is increased for small attack angles and the astern attack angle compared to fast target. Obviously, some type of a breaking point is experienced for target speed of .4 or less of torpedo speed.

Why a slow target produces this increase in MOE in the two extreme cases (ahead and astern) may be explained by the balance between time to reach detection range and the total relative speed. It is, however, more difficult to give any explanation of why a slow target should produce a lower MOE for some attack angles than a faster target does. One would have anticipated an increase in MOE over the whole range of attack angles for a slow target.

Torpedo Parameters:

TO Speed 32 40Knots
 Lobe width 20 20°
 Sweep angle 40 30°
 Turn rate 15 18°/s

Tactical Situation:

Range 3000m
 Det. range 750m

One detection

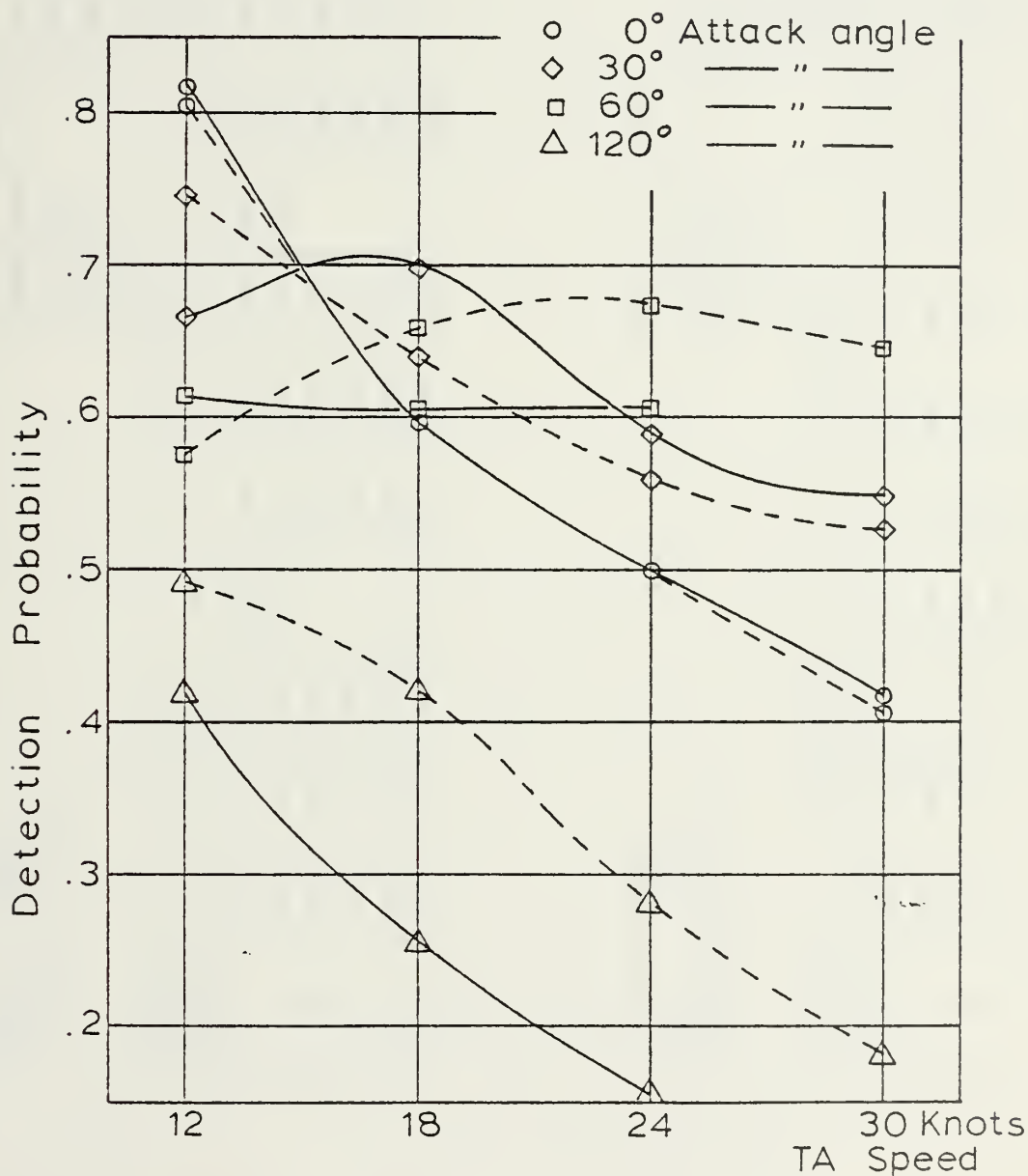


Figure 24 - COMPARISION OF TWO TORPEDOES WITH CHANGE IN TARGET SPEED

Tactical situation
Range 3000 m
Detection range 750 m

Torpedo parameters
Torpedo speed 32 knots
Sweep angle 40 degrees
Lobe width 20 degrees
Turn rate 15 deg/sec

Attack angle	1 detection			2 detections			3 detections			Target speed knots
	12	18	24	12	18	24	12	18	24	
0	.8200	.5933	.5000	.7067	.4733	.3800	.4667	.3600	.2533	.1867
30	.6667	.7000	.5867	.5467	.5667	.4600	.4200	.3667	.3267	.2867
60	.6133	.6067	.6067	.5533	.5067	.4533	.3933	.4267	.3667	
90	.4933	.4000	.3067	.3600	.3533	.2467	.3133	.2730	.2133	
120	.4200	.2533	.1533	.3267	.2133	.1267	.2400	.1733	.1067	
180	.4200	.2000	.0000	.3667	.2000	.0000	.2667	.1733	.0000	

Tactical situation
Range 3000 m
Detection range 750 m

Torpedo parameters
Torpedo speed 40 knots
Sweep angle 30 degrees
Lobe width 20 degrees
Turn rate 18 deg/sec

Attack angle	1 detection			2 detections			3 detections			Target speed knots
	12	18	24	12	18	24	12	18	24	
0	.8067	.5933	.5000	.6000	.4600	.3467	.4133	.2867	.1933	.1400
30	.7467	.6400	.5600	.6000	.5067	.4000	.4267	.3733	.3267	.3267
60	.5733	.6600	.6733	.4867	.5933	.5867	.3600	.4800	.5333	.4267
90	.4667	.4933	.4600	.4067	.4067	.3867	.3200	.2933	.3333	.2667
120	.4933	.4200	.2800	.4133	.3467	.2333	.2333	.2600	.1867	.1000
180	.5000	.2267	.2000	.3733	.2000	.1467	.2467	.2000	.0067	

Table VIII - VARIATION IN TARGET SPEED

VII. TACTICAL ANALYSIS

In addition to the detailed parametric analysis, which has been shown previously, we also could expand the analysis to cover more tactical related problems. If we assume a given target speed, we could construct detection probability charts as shown in Fig. 25. a. and b.

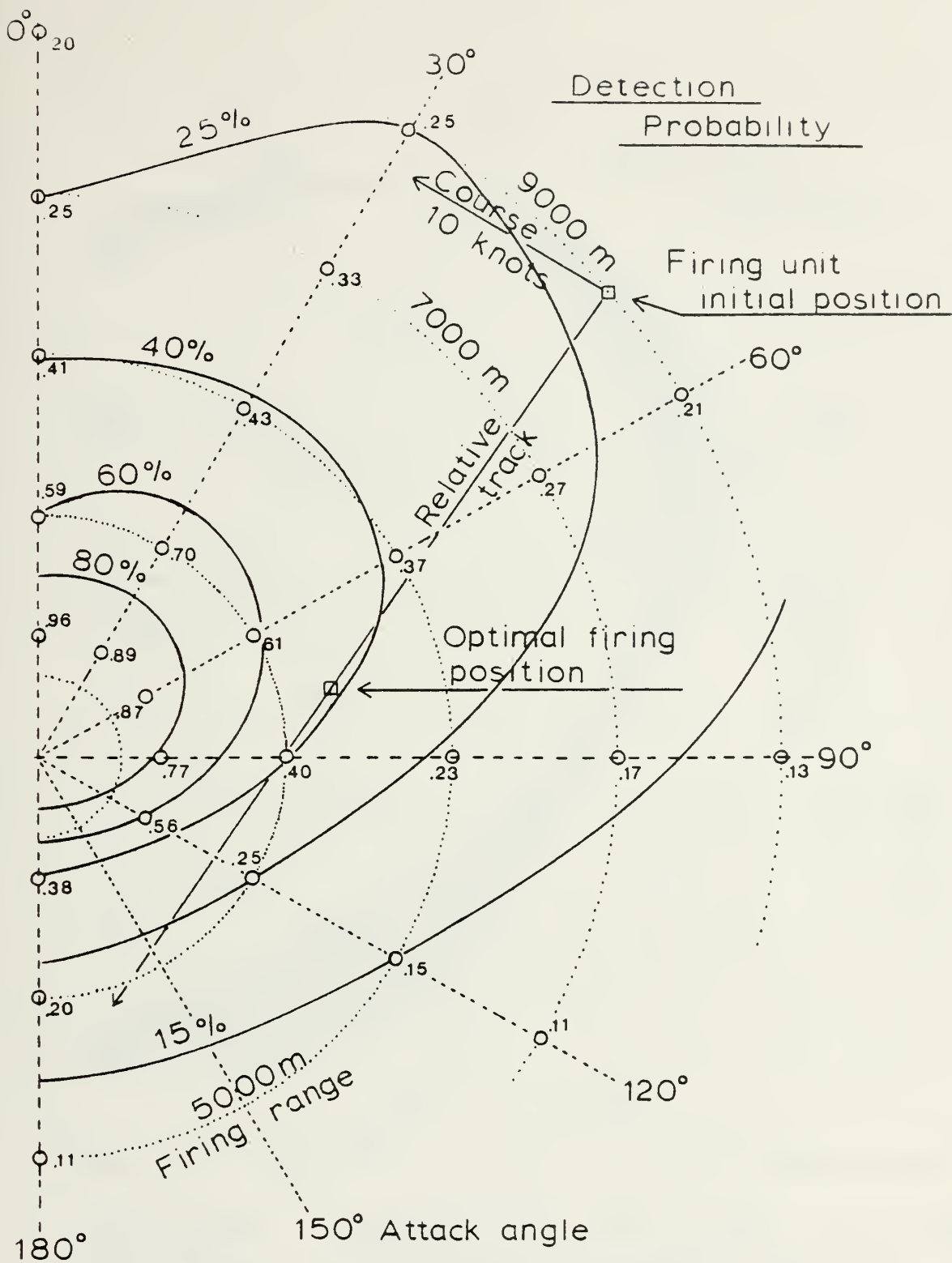
This analysis would then naturally fall into two areas:

- direct comparison of two or more different types of torpedoes.
- effect of tactical situation on the detection probability.

The two charts (Figs. 25.a. and b.) were formed by running simulation runs for different tactical situations (range and attack angle), and then fitting constant detection probability curves through the data points.

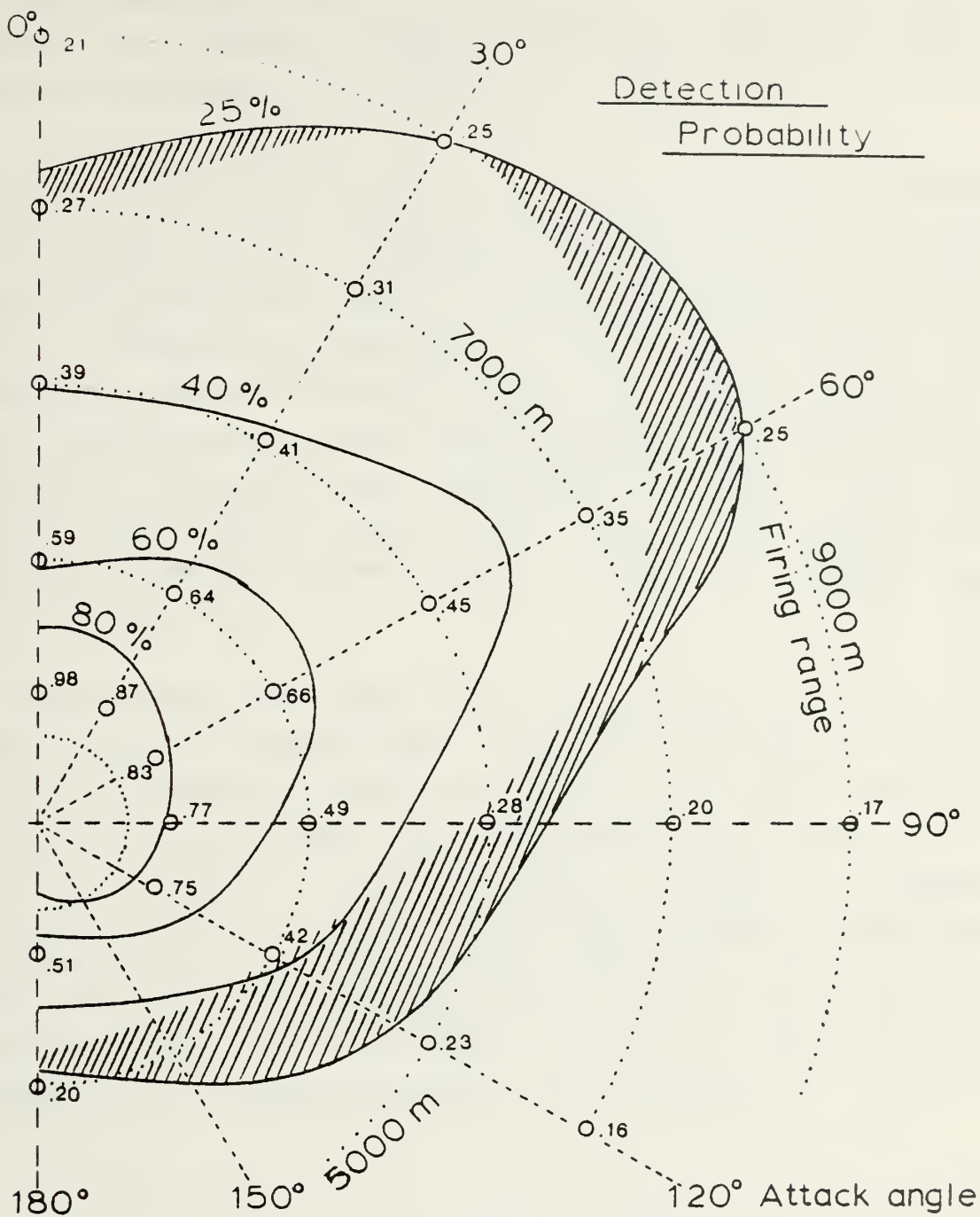
The use of these types of charts falls into two areas: Evaluate different torpedo types for different tactical situations; essentially, which torpedo is best. Or for a given tactical situation, how could the situation be improved, and what options exist.

The first type of use applies mainly to operational planning; operational requirement in the design phase of a torpedo and procurement. By laying one chart atop of the other; we get a visual picture of how much is improved when using a 'better' torpedo, and for which tactical situation. The shaded area in Fig. 25.b. shows how many more tactical situations have been covered when going from a 32 knots torpedo to a 40 knots torpedo for 0.25 detection probability.



Det. range	750 m	TO Speed	32 Knots
TA Speed	18 Knots	Sweep angle	40°
Turn rate	15 %s	Lobe width	20°

Figure 25 - EXAMPLE OF TACTICAL GUIDELINES



Det. range	750 m	TO Speed	40 Knots
TA Speed	18 Knots	Sweep angle	30 °
		Lobe width	20 °
		Turn rate	18°/s

Figure 25.b. - EXAMPLE OF TACTICAL GUIDELINES

The other type of use of the charts is tactical. When a firing unit decides to attack, and finds itself in a given tactical situation, the question is: What to do ?

For given target speed and own max speed, the charts make it possible in a simple way to decide where to go and what course to keep. Also from the charts, one can decide where on the relative course is the optimal firing position. For a submarine attacking a zig-zagging target, the Commanding Officer can better make his evaluation of when to fire, as the attack angle and the distance are continuously changing. He can see what improvement to expect when the target will change course next time. An example of a tactical situation and the course of action to follow are given in Fig. 25.a.

These points also bring up the question of what to improve in the operational picture; the firing unit's ability to achieve a good firing position or the torpedo's ability to detect target from non-optimal situations. In this discussion, the guided torpedo has to be brought into the picture. The effectiveness of guidance has not been addressed at all in this study, basically because that would have significantly expanded the scope of the study, as well as bringing in the whole problem of fire control equipment, its effectiveness and its reliability.

VIII. CONCLUSIONS

The study was carried out in order to investigate the detection process of an active sonar homing torpedo used against surface ships.

Specifically, we wanted to study the effect of changes in torpedo parameters such as torpedo speed, turn rate, sweep angle and detection range, as well as changes in the tactical situation such as target speed, firing range and attack angle.

In an attempt to gain insight into the complexity of a homing torpedo, the described model was built and the simulations done as previously shown.

In designing a homing torpedo and evaluating torpedo tactics the detection probability is an essential part of the total effectiveness of the torpedo. To be able to hit the target, the torpedo has first to detect it, which justifies why we started out with analyzing the detection process.

Also, as part of this analysis we investigated certain aspect of the next step in the operational process; acquisition.

It is not difficult to visualize tests which may be used in order to recognize an echo as a detection and subsequently a target to attack. Some of these tests may be doppler, successive detections, detections within a given range, 2-of-3 detections, size of echo, length of echo etc.

The problem of false echo, however, was not approached in

this study. That would have to be the next to consider in relation to reducing the number of successive detections in order to acquire a target.

In order to allow for the errors in tracking of the target before firing and also small maneuvering of the target after firing, we introduced errors in the target speed and course when calculation of the torpedo main firing course was done.

During runs the torpedo was unguided, and did not react on any detection; i.e. it did not attack the target. For sonar condition, isovelocity was assumed and no surface effect was built into the model.

The result gave certain insight into the complexity of the detection process, stressing the importance of a good tactical firing position, and of a high speed torpedo with long detection range.

However, the data also showed the relationship between detection range, lobe width and turn rate, as well as weighting the sweep angle in relation to torpedo speed. It can also be concluded from the results that changes in torpedo parameters as turn rate and sweep angle, which may be inexpensive modifications, will not give a significant improvement.

Generally, the overall important factor was the time the torpedo used in order to travel within the detection range of the target. This was due primarily to the error generated in the target data, obviously the actual value of the result is sensitive to these assumptions. However, the understanding and insight in the detection process achieved by simulation should not be reduced by other assumptions with regard to error in target data.

With regard to the analysis, the result has shown a consistent and general trend that if we are able to require only one detection for acquiring a target, the detection probability is significantly higher than if more than one detection is required. And what is more important, the potential for improving/optimizing a homing torpedo is also significantly higher for one detection only. This implies a large payoff for other methods of keeping down the probability of false detections.

Secondly, a high speed torpedo has shown a general superiority in MOE. This was specially obvious in attack angles greater than 90 degrees, which tends to make a high speed torpedo more of an all-round/reliable torpedo with regard to tactical situations.

Thirdly, except for changes in attack angle and firing range, the detection range seems to influence the MOE strongly.

These three remarks all point towards an improvement in the sonar-/filtering-area as the most promising area in which to carry out research and invest effort.

This study has also pointed out the advantage of high torpedo speed and firing at short ranges. There exists therefore considerable argument for a short range, high speed torpedo, given that one is able to position the torpedo at a short firing range; i.e. a small, simple torpedo.

Basically, there are two schools of thought;

- a highly sophisticated torpedo; long range, guidance, expensive, but close to the one shot-one hit idea.
- a simple, high speed torpedo; short range,

non-guidance, inexpensive, and requiring either a firing unit which can get into an optimal firing position or a larger number of shots to achieve hit.

The result may be useful in giving example of how tactical guidelines can be evaluated by the simulation approach. But more significant is pointing out the importance of torpedo capability and the tactical situation. Obviously, we have to look on the whole torpedo system, including the firing unit. Investment in resources and effort should not necessarily be spent only on the torpedo in order to increase its effectiveness, but may be spent on the firing unit as well in order to make the unit able to reach a better firing position.

A follow-on of this study may be to investigate the attack process of the torpedo, including the acquisition-and hit-problem.

Then the question of guidance during torpedo run should be analyzed in order to better evaluate the problem of choosing between a few sophisticated, expensive, guided torpedo system or many simple, inexpensive, nonguided torpedo systems.

APPENDIX A

PRINT CUT OF SIMULATION PROGRAM

```

C C C
A TORPECC SIMULATION. HCMING TORPECC DURING SEARCH.
  SIMULATING AN ACTIVE IN 0.5 SEC STEPS.
  THE PROGRAM IS RUN IN TC, TA, TRATE, RANGE, ALFA, LAMEC, TADEC,
  COMMON ISEEC2, TTIME, TCOR, BNG, PH2, MCCURS, TCCURS,
  *EVAR, RAD, TAC, CCOR, DEVSP, BNG, FN, PH2, MCCURS, TCCURS,
  *MXT, MXM, INTVAL, ICTIME, ITIME, XT, YT, XTAR, YSTAR, NCIST,
  *TURN, TC, INTVAL, PFI, RMAX(5,6), TRANGE, DIST, IPRINT
  COMMON/TARGET/TACMG, TAM1, RANGMCC, CAL, COUR, CE(10), SE(15), JRUN,
  *IFLAG, LA2
  DIMENSION RM(5,5), VAR(5), DET(150,5), DETB(150,5), STD(5),
  *ASPEC(150,5), DERB(150,5), CLCSB(150,5), KCN(150,5),
  *REAL, LAMBC, MCOURS, MXT, MXM, NCIST, LAMECC
  INTEGER RUNCLT

C SETTING OF CONSTANTS (STEP 1)
  CALL CVFLCN
  PF1=3.141592654
  PF2=2.*PHI
  RAD=PH2/360
  ISEEC1=362776
  ISEEC2=361655
  CCORC=15
  CCORC=CCORC*RAC
  CCORC=CCORC*ST DEV IN TARGET SPEED ESTIMATE
  CSPEED=3
  DEVCF=CSPEED*0.5
  ICTIME=1

C SET NUMBER OF ITERATIONS
  IRUN=150

C SET PRINT CUT MCODE
  IPRINT=1

C SET LCBE OFF TORPECC CENTER BEARING
  CFLCB=0.

C SET TABLES TO ZERC (STEP 2)
  CC 11 I=1,5
  CC 12 J=1,5
  RM(1,J)=0.
  CC CONTINUE
  CC 13 J=1,5
  CC 14 I=1,5
  KCN(I,J)=0

```

12
11


```

14 CCNTINUE
13 CCNTINUE
C  CA2=C.
C  CCMPUTE TARGET ERRORS AND STORE
C  CC 20 I=1,C
C  CE(I)=-((15.*RAD+CCCR/10.)+(CCOR/10.)*I*2.
C  CCNTINUE
C  SE(1)=-1.8737*DEVSP
C  SE(2)=-1.2825*DEVSP
C  SE(3)=-1.568*DEVSP
C  SE(4)=-0.7285*DEVSP
C  SE(5)=-0.525*DEVSP
C  SE(6)=-0.34*DEVSP
C  SE(7)=-0.1675*DEVSP
C  SE(8)=0*DEVSP
C  SE(9)=0.1675*DEVSP
C  SE(10)=0.34*DEVSP
C  SE(11)=0.525*DEVSP
C  SE(12)=0.7285*DEVSP
C  SE(13)=0.568*DEVSP
C  SE(14)=1.2825*DEVSP
C  SE(15)=1.8737*DEVSP
C  CC 500 JRUN=1,IRUN
C  SET RUN CCOUNTERS (STEP 3)
C  IFLAG=1; TCC LCW TCRPECC SPEED
C  IFLAG=0
C  ICCNT=0
C  JCCNT=0
C  JTIME=0
C  IL=C
C  IH=C
C  CIST=0.
C  CXT=0.
C  MXM=0.
C  RUNCT=C
C  REAC IN SETTING(TCRP AND TACTICAL)
C  FIRST RUN ? (STEP 4)
C  IF(JRUN.GT. 1)GO TO 160
C  CALL PAFMET
C  WRITE(6,228)CFLCB
C  FCFMAT(1X,/,1X,*,SCNAR MAIN LCBE CFF-SET FROM CENTER ',
228 *BEARING',F6.2,*,TIMES DEFLECTION ANGLE',/)

```

```

TCR000490C
TCR000510C
TCR000520C
TCR000530C
TCR000540C
TCR000550C
TCR000560C
TCR000570C
TCR000580C
TCR000590C
TCR000600C
TCR000610C
TCR000620C
TCR000630C
TCR000640C
TCR000650C
TCR000660C
TCR000670C
TCR000680C
TCR000690C
TCR000700C
TCR000710C
TCR000720C
TCR000730C
TCR000740C
TCR000750C
TCR000760C
TCR000770C
TCR000780C
TCR000790C
TCR000800C
TCR000810C
TCR000820C
TCR000830C
TCR000840C
TCR000850C
TCR000860C
TCR000870C
TCR000880C
TCR000890C
TCR000900C
TCR000910C
TCR000920C
TCR000930C
TCR000940C
TCR000950C
TCR000960C

```


23	CCETE(JRUN,J)=0.	TORC145C
	DET(JRUN,J)=0.	TORC146C
	ASPEC(JRUN,J)=0.	TORC147C
	CLCSB(JRUN,J)=0.	TORC148C
	CLCSB(JRUN,J)=0.	TORC149C
	CCCONTINUE	TORC150C
499	GC TO 9C0	TORC151C
50C	IF(JFLAG.EC. 1)GC TO 990	TORC152C
	IF(MXT.GE. TRANGE)RLNCUT=1	TORC153C
	IF(RUNCUT.EQ. 1)GC TO 990	TORC154C
	CALCULATE NEW PCSTIONS	TORC155C
	CALL PCSTIS	TORC156C
	CHECK IF TARGET IS DETECTED	TORC157C
	CALL DETECT	TORC158C
	CHECK CPA(CLOSEST POINT OF APPRCHCT) (STEP 8)	TORC159C
	IL=IL+1	TORC160C
	IF(IL.LE. 20)GO TC 500	TORC161C
	IL=0	TORC162C
155	CPA=DIST	TORC163C
	IF(CPA1-CPA .LE. 0.)RUNCUT=1	TORC164C
	CPA1=CPA	TORC165C
	GC TC 500	TORC166C
	GENERATE STATISTICS (STEP 9)	TORC167C
	CCCONTINUE	TORC168C
	CC 510 IKL=1,5	TORC169C
	KCN() = DETECTION/NO DETECTION	TORC170C
	IF(FMAX(IKL,1) .GT. 1.)KON(JRUN,IKL)=1	TORC171C
	DET() = DISTANCE TC TARGET AT DETECTION	TORC172C
	DET(JRUN,IKL)=RMAX(IKL,1)	TORC173C
	CEIB() = BEARING TC TARGET AT DETECTION	TORC174C
	CEIB(JRUN,IKL)=RMAX(IKL,2)	TORC175C
	ASPEC() = TARGET ASPECT AT DETECTION	TORC176C
	ASPEC(JRUN,IKL)=RMAX(IKL,5)	TORC177C
	CLCSB() = BEARING TC CLCSEST PART OF TARGET	TORC178C
	CLCSE(JRUN,IKL)=RMAX(IKL,4)	TORC179C
	CERE() = REL BEARING FROM MAIN TCRP COURSE TC TARGET	TORC180C
	CERE(JRUN,IKL)=RMAX(IKL,6)	TORC181C
	CCCONTINUE	TORC182C
51C		TORC183C
		TORC184C
		TORC185C
		TORC186C
		TORC187C
		TORC188C
		TORC189C
		TORC190C
		TORC191C
		TORC192C


```

C
C
IF(IFLAG .EQ. 1)GC TO 991
PRINT OUT (STEP 10)
CCUR=MCCURS/RAD
TC=TCOLRS/RAD
IT=ITIME/2
IF(IPRINT .EQ. 0)GC TO 195
WRITE(6,232)RUN,TACMG,TAM1,RNGMCC,DAL,COUR,XT,YT,XIAP,YTAR,
*IT,MXT(1X,/,1X,I3,3X,F5.1,2X,F4.1,1X,F6.0,2X,F5.1,3X,
232 *FCR,1,7X,F6.0,1X,F6.0,2X,F6.0,1X,F6.0,3X,I4,2X,F6.0)
*IF(RMAX(1,1).EQ. 0.)GC TO 991
GC TO 500
WRITE(6,200)IT
FCR MAT(1X,/,RUN STOPPED AFTER ',I5,' SECONDS',//,
200 *1X,/,RUN DATA AS FOLLOWS AT END CF RUN')
*IF(6,202)MXT,DIST
FCR MAT(1X,/,TOTAL TCRP RUN ',F9.1,/,1X,'DIST TC TARGET ',F9.1)
202 *FCR MAT(1X,/,XT,YT,XIAP,YTAR,COUR,TC
*FCR MAT(1X,/,TCRP X-CORC ',2X,F9.1,4X,'TCRP Y-CORC ',2X,F9.1,/,
204 *1X,/,TARGET X-CORC ',F9.1,4X,/,TARGET Y-CORC ',F9.1,/,
*1X,/,TORP MAIN COURSE ',F9.3,6X,/,TCRP COURSE ',1X,F5.3}
*IF(RMAX(1,1).EQ. 0.)GC TO 991
WRITE(6,206)
206 *FCR MAT(1X,/,J=1,5),I=1,5)
*1X,/,MAXIMUM DETECTION RANGES AND BEARINGS',
*1X,/,SUCCESSIVE',4X,/,MAX DET BEARING',
*5X,/,MAX DET BEARING',4X,/,TARGET',/,
*1X,/,CENTER',9X,/,RANGE - CLOSEST',4X,/,CLOSEST',
*EX,/,ASPECT')
*FCR MAT(1X,/,I4,7X,F10.1,7X,F8.2,7X,F10.1,9X,
208 *F6.2,7X,F8.2)
GC TO 500
991 *WRITE(6,220)
C
C
C
ALL RUN COMPLETED ? (STEP 11)
CC CONTINUE
CALCULATE SUMMARY RESULT (STEP 12)
CC 27 KR=1,5
CC 28 IF=1,IRUN
RM(KR,1)=RM(KR,1)+FLOAT(KON(LR,KR))
RM(KR,2)=RM(KR,2)+CET(LR,KR)
RM(KR,3)=RM(KR,3)+ABS(ASPEC(LR,KR))
RM(KR,4)=RM(KR,4)+DET(LR,KR)
RM(KR,5)=RM(KR,5)+CETB(LR,KR)
CC CONTINUE
28

```



```

C C (STEP A5)
C LEVEL CF VARIATION: 20-30-40 DEGREES
C ALFAG=30.
C ALFA=ALFAG*RAD
C
C LAMEDG - LCBE WICHT EACH SIDE CF TCRP HEADING (STEP A6)
C LEVEL OF VARIATION: 10-20-30 DEGREES
C LAMEDC=20.
C LAMED=LAMBDG*RAD
C
C RELERG - RELATIVE BEARING FROM TARGET TO TORP IN DEGREE (STEP A7)
C LEVEL OF VARIATION: 0-30-60-90-120-180 DEGREES
C RELERG=-60.
C RELER=RELBRG*RAD
C
C RANGE - DISTANCE BETWEEN TARGET AND TCRP (STEP A8)
C LEVEL CF VARIATION: 1500-3000-5000-7000 METERS
C RANGE=3000.
C
C TRANGE - MAX TCRP RUN IN METERS (STEP A9)
C TRANGE=18000.
C
C TRATEG - TCRP TURNRATE IN DEGREE PER SEC (STEP A10)
C LEVEL OF VARIATION: 3-6-9-12-15-18-21 DEGREE/SEC
C TRATEG=18.
C TRATE=TRATEG*RAD
C
C CALCULATE WIDTH OF TACTICAL SWEEP-LANE (THEORETICAL)
C SRNG=TATEC*SIN(ALFA+LAMBD)*2.
C
C CALCULATE CCVERAGE RATIO (THEORETICAL)
C CRATIO=1.-(TRATE*TIME)/(2.*LAMBD)
C
C PRINT OF SITUATION AT START CF RUN (STEP A12)
C IF(IPRINT.EQ.0)GC TO 90
C WRITE(6,11C)
C FCFMAT(IX,/,1X,'TACTICAL SITUATION WHEN FIRING',6X,
C *TCRPECC,PARAMETER',/,
C *2X,'RANGE ATTACK TARGET TARGET',6X,'TEC.CET TORP',
C *3X,'SWEEP LORE TURN SWEEP CCVERAGE',/,
C *5X,'ANGLE COURSE SPEED',2X,
C *,'ANGLE WICHT RATE LANE',4X,'RATIO',
C *WRITE(6,112)RANGE,RELBRG,TACK,TEDEC,TCKN,ALFAG,
C *LAMEDG,TRATEG,SRNG,CRATIO
C FCFMAT(1X,F6.0,2X,F6.1,3X,F4.1,3X,F5.1,3X,F5.1,3X,
C *F4.1,3X,F4.1,2X,F4.1,2X,F6.1,3X,F6.3)
C GC TO 90
C WRITE(6,11C)

```

```

TORC337C
TORC338C
TORC339C
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TORC384C

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100  FCFMAT(1X, 'TACTICAL SITUATION WHEN FIRING',/,1X,
    *  F FIRING RANGE',3X, 'ATTACK ANGLE',3X,
    *  T TARGET COURSE',2X, 'TARGET SPEED',)
101  FCFMAT(1X,4(2X,F6.1,7X),/)
102  FCFMAT(1X,4(2X,F6.1,7X),/)
103  FCFMAT(1X,4(2X,F6.1,7X),/)
104  FCFMAT(1X, 'TORPEDC PARAMETERS',/,1X,
    *  T TORPEDC RANGE',2X, 'TRANS.INT.VAL',2X, 'TORP SPEED',3X,
    *  T TORPEDC ANGLE',)
105  FCFMAT(1X,2(2X,F7.2,7X),2(F6.1,7X),/)
106  FCFMAT(1X,2(2X,F7.2,7X),2(F6.1,7X),/)
107  FCFMAT(1X,2(2X,F7.2,7X),2(F6.1,7X),/)
108  FCFMAT(1X, 'LOBE WIDTH',6X, 'TURN RATE',/,
    * 3X,F6.1,10X,F6.1)
109  FCFMAT(1X, 'SRNG',CRATIC
    *  T THEORETICAL WIDTH OF TACTICAL SHEEP-LANE',F9.1,
    *  T THEORETICAL COVERAGE RATIO',F9.4)
110  RETURN
111  END

SUBROUTINE FIRING
  CALCULATE THE TORP DEFLECTION ANGLE, MAIN CCOURSE, FIRING CCOURSE
  BASED ON ESTIMATE OF TARGET DATA(UNCERTAINTY)

  DIMENSION U(2)
  COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBC, TACEC,
  * BEAR, RAD, TAC, CCCR, DEVSP, BNG, FN, PH2, ACCURS, TCCURS,
  * MXM, MXN, IK, IDTIME, XT, YT, XTAR, YTAR, ICIST,
  * NCIST, TURNIC, INIVAL, PHI, RMAX(5,6), TRANGE, DIST, IPRINT
  COMMON/CATA/DA, OFLCB
  COMMON/TARGET/TACMG,TAM1,RNGMOD,CA1,COUR,CE(1C),SE(15),JRUN,
  * IFLAG,CA2
  REAL LAMBDO, MCOURS, MXT, MXM, NCIST, LAMELC
  INTEGER RUNCUT

  PN=-1
  PP=1
  KSFEEC=MOD((JRUN-1),15)+1
  KCCURS=IFIX((JRUN-1)/15.)+1
  CALL GGUR(ISEED2,2,U)

  CALCULATE ESTIMATE OF TARGET CCOURSE (STEP B1)
  TACM=TAC+CE(KCCURS)
  DIFCC=TACM-TAC
  IF (TACM.GE. PH2) TACM=TACM-PT2

```


C C C C

```

SLEFOUTLINE DETECT
TC CHECK IF TARGET IS DETECTED AND STORE DETECTION DATA
COMMON ISEED2, TTIME, TC, TA, TRATE, RANGE, ALFA, LAMBD, TADCC,
*BEAR, RAD, TAC, CCOR, DEVSP, BNG, FN, PH2, ACCURS, TCCURS,
*MXM, MXM, IK, IDTIME, ITIME, XT, YI, XTAR, YIAR, ICIST,
*MCIST, TURNTO, INTVAL, PHI, RMAX(5,6), TRANGE, CIST, IPRINT
CCMNCN/CATA/CA, OFLCB
REAL LAMBD, MCOURS, MXT, MXM, MCIST, LAMBDG
INTEGER RUNCUT
DIMENSION DE(3,2)
DOUBLE PRECISION B, REX1, RBX2, X1, X2, X3, XX1,
*V1, V2, V, U, FIFACT, X01, X02, X03, XX2, PCWER, RELB, ALAM
SETTING CF TARGET DIMENSION, A - TARGET LENGTH,
E - TARGET WIDTH, C - TARGET DEPTH. (STEP C1)
A=100.
E=15.
C=4.

```

C C C

```

CHECK IF TRANSMISSION (STEP C2)
IF(1K.LT. INTVAL)GC TO 20
IT=0
CALCULATE RANGE TC TARGET (STEP C3)
C1FX=XTAR-XI
C1FY=YTAR-YI
C1ST=SQRT((C1FX**2)+(C1FY**2))
TEST IF TARGET IS WITHIN POSSIBLE DETECTION RANGE
IF(CIST.GT.(TADCC+A/2.))GC TC 20

```

C C

```

DETECTION THRESHOLD (STEP D4)
PCWMAX=1./((B*TADCC)**4
L=SCALE(PHI/2.)
CCNST=(A**2)*(B**2)*(C**2)
PCWMAX=CCNST*PCWMAX*U
CALCULATE TIME TC TARGET (STEP C5)
TIMCL1=CIST/1500.
XTAR1=XTAR+SIN(TAC)*(TIMDL1*TA)
YTAR1=YTAR+COS(TAC)*(TIMDL1*TA)

```

C C

C

TCR05250
TCR05310
TCR05320
TCR05330
TCR05340
TCR05350
TCR05360
TCR05370
TCR05380
TCR05390
TCR05400
TCR05410
TCR05420
TCR05430
TCR05440
TCR05450
TCR05460
TCR05470
TCR05480
TCR05490
TCR05500
TCR05510
TCR05520
TCR05530
TCR05540
TCR05550
TCR05560
TCR05570
TCR05580
TCR05590
TCR05600
TCR05610
TCR05620
TCR05630
TCR05640
TCR05650
TCR05660
TCR05670
TCR05680
TCR05690
TCR05700
TCR05710
TCR05720
TCR05730
TCR05740
TCR05750


```

C C V=(V1+V2)*2
C C COMPUTE SCALING FACTOR DUE TO ASPECT (STEP C11)
C C L=SCALE(RELB)
C C FIFACT=L/V
C C CALCULATE RETURN TIME FOR ECHC (STEP C12)
C C TIMCL2=2.*TIMDLI
C C CALCULATE REL BEARING FOR RETURNING ECHO (STEP D13)
C C TURNST=TRATE*TIMCL2
C C TXDC=TCCLRS+SIGN(TURNST,FN)
C C TXCC=ABS(MCCURS-TXDC)
C C IF(TXCC.GT.PHI)TXCC=PH2-TXDC
C C IF(TXDC.LE.ALFA)GC TC I8
C C ALF=TXCC-ALFA
C C RELTO=RELO-SIGN((TURNST-ALF),PN)+SIGN(ALF,FN)
C C GC TO I9
C C RELTO=RELO-SIGN(TURNST,FN)
C C RELDIF=RELTC-RELO
C C RELT1=REL1+RELDIF
C C RELT2=REL2+RELDIF
C C IF(RELTC.GT.PHI)RELT0=PH2-RELTC
C C IF(RELTC.LT.-PHI)RELT0=PH2+RELTC
C C IF(RELT1.GT.PHI)RELT1=PH2-RELT1
C C IF(RELT1.LT.-PHI)RELT1=PH2+RELT1
C C IF(RELT2.GT.PHI)RELT2=PH2-RELT2
C C IF(RELT2.LT.-PHI)RELT2=PH2+RELT2
C C TEST FOR DCFPLER
C C FRQCEF=50.*2.*(TO*CCS(DC)-1.)/1500.
C C FRQCIF=50.*2.*(TO*CCS(DC)+1.)/1500.
C C RELC=RELB
C C FRCSF=50.*2.*(TO*CCS(DD)+TA*CCS(FELC))/1500.
C C IF((FRQSF.LT.FRQDIF).AND.(FRCEDEF))GC TC 2C
C C CALCULATE RANGE AND BEARING TO CLOSEST PART OF TARGET (STEP C14)
C C CE(1,1)=DIST
C C CE(1,2)=RELTC+DD
C C CE(2,1)=DIST1
C C CE(2,2)=RELTI1+DD
C C CE(3,1)=DIST2
C C CE(3,2)=RELTI2+DD
C C CMIN=CB(1,1)
C C MC=1
C C IF(CMIN.GT.DB(2,1))GO TO I0
C C IF(CMIN.GT.CB(3,1))GC TO I1
C C GC TO I2

```

TTCRC625C
TTCRC6260
TTCRC6270
TTCRC6280
TTCRC6290
TTCRC6300
TTCRC6310
TTCRC6320
TTCRC6330
TTCRC6340
TTCRC6350
TTCRC6360
TTCRC6370
TTCRC6380
TTCRC6390
TTCRC6400
TTCRC6410
TTCRC6420
TTCRC6430
TTCRC6440
TTCRC6450
TTCRC6460
TTCRC6470
TTCRC6480
TTCRC6490
TTCRC6500
TTCRC6510
TTCRC6520
TTCRC6530
TTCRC6540
TTCRC6550
TTCRC6560
TTCRC6570
TTCRC6580
TTCRC6590
TTCRC6600
TTCRC6610
TTCRC6620
TTCRC6630
TTCRC6640
TTCRC6650
TTCRC6660
TTCRC6670
TTCRC6680
TTCRC6690
TTCRC6700
TTCRC6710
TTCRC6720


```

10 CMIN=CE(2,1)
   MC=2
   GC TC 5
11 CMIN=CB(3,1)
   MC=3
12 EFEL=CE(MC,2)
   IF(BREL.GT. PHI)BREL=PH2-BREL
   IF(EREL.LT. -PHI)BREL=PH2+BREL
C
C   CALCULATE RECEIVING GAIN FACTOR (STEP D15)
   REX1=RELT1
   REX2=RELT2
   REX3=RELT3
   XC1=XFACT(REX1,ALAM)
   XC2=XFACT(REX2,ALAM)
   XC3=XFACT(REX3,ALAM)
   XX2=(XC1+XC2+XC3)/3.
C
C   CALCULATE FRACTION OF POWER IN TO RECIEVER (STEP D16)
   PCWR=CCNST*XX1*XX2*FIFACT/(DIST**4)
C
C   TEST FOR DETECTION THRESHOLD (STEP D17)
   IF(PCWR.LT. POWMAX)GC TC 15
C
C   COMPLETE BEARING RATE (STEP D18)
   ASP=RB+PHI-TAC
   IF(ASP.GT. PHI)ASP=ASP-PH2
   IF(ASP.LT. -PHI)ASF=PH2+ASP
   AF=ASP*RELT3
   TACS=TA*SIN(ABS(ASP))
   TCCS=TO*SIN(ABS(RELT3))
   ERATE=(TACS+SIGN(TCCS,AP))/DIST
C
C   CHECK BEARING RATE AGAINST TURNRATE (STEP D19)
   IF(ERATE.GE. TRATE)GC TO 15
C
C   CHECK TCRPEDO SPEED ADVANTAGE (STEP D20)
   TALS=TA*CCS(ABS(ASP))
   TCLS=TC*CCS(ABS(RELT3))
   IF(AES(ASP).GT. PHI/2.)TALS=-TALS
   IF(AES(RELT3).GT. PHI/2.)TCLS=-TCLS
   IF((TALS+TCLS).LE. 0.)GC TC 15
C
C   FILE=RE-MCGLFS
   IF(RLB.GT. PHI)RLB=RLB-PH2
   IF(RLB.LT. -PHI)RLB=PH2+RLB
C

```

```

TORC673C
TORC674C
TORC675C
TORC676C
TORC677C
TORC678C
TORC679C
TORC680C
TORC681C
TORC682C
TORC683C
TORC684C
TORC685C
TORC686C
TORC687C
TORC688C
TORC689C
TORC690C
TORC691C
TORC692C
TORC693C
TORC694C
TORC695C
TORC696C
TORC697C
TORC698C
TORC699C
TORC700C
TORC701C
TORC702C
TORC703C
TORC704C
TORC705C
TORC706C
TORC707C
TORC708C
TORC709C
TORC710C
TORC711C
TORC712C
TORC713C
TORC714C
TORC715C
TORC716C
TORC717C
TORC718C
TORC719C
TORC720C

```


C	STCRE DETECTION DATA (STEP D21)	TCR0721C
C	JCCNT=JCCNT+1	TCR0722C
C	JMAX=MAX0(JMAX,JCCNT)	TCR0723C
	JCCNT=JCCNT	TCR0724C
	IF (JCCNT .GE. 5) JCCNT=5	TOR0725C
		TCR0726C
		TOR0727C
		TCR0728C
		TCR0729C
		TCR0730C
25	LECTICNS (STEP D22)	TOR0731C
30	GC TO (30,31,32,33,34), ICONT	TOR0732C
	IF (RMAX(1,1) .NE. 0.) GO TO 20	TORC733C
	RMAX(1,1)=DIST	TCR0734C
	RMAX(1,2)=(REL TO+DC)/RAD	TCR0735C
	IF (RMAX(1,2) .GT. 180.) RMAX(1,2)=RMAX(1,2)-360.	TORC736C
	RMAX(1,3)=DMIN	TCR0737C
	RMAX(1,4)=BREL/RAC	TCR0738C
	RMAX(1,5)=RELA/RAC	TORC739C
	RMAX(1,6)=RLB/RAC	TCR0740C
	GC TO 20	TOR0741C
31	IF (RMAX(2,1) .NE. 0.) GO TO 20	TCR0742C
	RMAX(2,1)=DIST	TCR0743C
	RMAX(2,2)=(REL TO+CC)/RAD	TORC744C
	IF (RMAX(2,2) .GT. 180.) RMAX(2,2)=RMAX(2,2)-360.	TCR0745C
	RMAX(2,3)=DMIN	TCRC746C
	RMAX(2,4)=BREL/RAC	TOR0747C
	RMAX(2,5)=RELA/RAC	TCR0748C
	RMAX(2,6)=RLB/RAC	TOR0749C
	GC TO 20	TOR0750C
32	IF (RMAX(3,1) .NE. 0.) GO TO 20	TCR0751C
	RMAX(3,1)=DIST	TOR0752C
	RMAX(3,2)=(REL TO+CC)/RAD	TCR0753C
	IF (RMAX(3,2) .GT. 180.) RMAX(3,2)=RMAX(3,2)-360.	TORC754C
	RMAX(3,3)=DMIN	TORC755C
	RMAX(3,4)=BREL/RAC	TCR0756C
	RMAX(3,5)=RELA/RAC	TOR0757C
	RMAX(3,6)=RLB/RAC	TCR0758C
	GC TO 20	TOR0759C
33	IF (RMAX(4,1) .NE. 0.) GO TO 20	TOR0760C
	RMAX(4,1)=DIST	TOR0761C
	RMAX(4,2)=(REL TO+CC)/RAD	TOR0762C
	IF (RMAX(4,2) .GT. 180.) RMAX(4,2)=RMAX(4,2)-360.	TORC763C
	RMAX(4,3)=DMIN	TCR0764C
	RMAX(4,4)=BREL/RAC	TOR0765C
	RMAX(4,5)=RELA/RAC	TORC766C
	RMAX(4,6)=RLB/RAC	TCR0767C
	GC TO 20	TOR0768C
34	IF (RMAX(5,1) .NE. 0.) GO TO 20	


```

FMX(5,1)=DIST
FMX(5,2)=(RELTO+DD)/RAD
IF(RMAX(5,2).GT. 180.)RMAX(5,2)=RMAX(5,2)-360.

```

```

FMX(5,3)=DMIN
FMX(5,4)=BREL/RAD
FMX(5,5)=RELA/RAD
FMX(5,6)=RLB/RAD
GC TO 2C

```

```

IF NO DETECTION, SET DETECTION STATUS

```

```

ICCNT=0
JCCNT=C
RETURN
ENC

```

```

FUNCTION BEARIN(A,B,C,D)
TC CALCULATE BEARING FROM TCFECC TC TARGET

```

```

C1FX=A-C
C1FY=B-C
PH2=2.*3.141592654
R2C=PH2/360.
IF(C1FY.NE. 0.)GC TO 16
RE=SC.*RAD
IF(C1FX.LT. 0.)RE=RE+(180.*RAD)
GC TC 17
RE=ATAN2(DIFX,DIFY)
IF(RB.LT. C.)RB=RE+PI*2
BEARIN=RB
RETURN
ENC

```

```

FUNCTION XFACT(X,Y)
CALCULATE REDUCTION FACTOR IN TRANSDUCER GAIN CUE
TC RELATIVE BEARING OFF CENTER-HEADING CF TCRPEDO
CCLBLE PRECISION X,XFACT,X,Y
PH1=3.141592654
IF(X.EQ. C.)GO TC 10
XY=X/Y

```

```

XFACT=ABS((DCOS(X*0.5)*DSIN(XY*PI)))/(XY*PI)
RETURN
XFACT=1.

```

TORC7769C
 TORC7770C
 TORC7771C
 TORC7772C
 TORC7773C
 TORC7774C
 TORC7775C
 TORC7776C
 TORC7777C
 TORC7778C
 TORC7779C
 TORC7780C
 TORC7781C
 TORC7782C
 TORC7783C
 TORC7784C
 TORC7785C
 TORC7786C
 TORC7787C
 TORC7788C
 TORC7789C
 TORC7790C
 TORC7791C
 TORC7792C
 TORC7793C
 TORC7794C
 TORC7795C
 TORC7796C
 TORC7797C
 TORC7798C
 TORC7799C
 TORC7800C
 TORC7801C
 TORC7802C
 TORC7803C
 TORC7804C
 TORC7805C
 TORC7806C
 TORC7807C
 TORC7808C
 TORC7809C
 TORC7810C
 TORC7811C
 TORC7812C
 TORC7813C
 TORC7814C
 TORC7815C
 TORC7816C


```

RETURN
END

```

```

C
C
C
C
C
C

```

```

FUNCTION SCALE(Y) FACTOR IN THE PROCESS CF
CALCULATE SCALING STRENGTH
COMPUTING TARGET
CCELE PRECISION SCALE,RELB,Z,Y
PHI=3.151552654
IF(Y.GT. PHI/2.) Y=PHI-Y
Z=C.251635*(Y**2) - C.18555*Y
Z=Z+0.0365*DSIN(3.*(Y+0.17453)) + C.015*(Y**2)*DSIN(5.*Y/2.)
SCALE=1./Z
RETURN
END

```

```

TCR0817C
TCR08180
TCR0819C
TCR0820C
TCR08210
TCR08220
TCR0823C
TCR08240
TCR0825C
TCR08260
TCR08270
TCR0828C
TCR08290
TCR0830C
TCR0831C
TCR0832C
TCR0833C

```


APPENDIX B

FLOW CHART FOR SIMULATION PROGRAM

A TORPEDO SIMULATION. MAIN PROGRAM.

PAGE 1

A TORPEDO SIMULATION. MAIN PROGRAM.

A TORPEDO SIMULATION.

SIMULATING AN ACTIVE HOMING TORPEDO GUIDING SEARCH.

THE PROGRAM IS RUN IN 0.5 SEC STEPS.

```
COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBC, TADFC,
      BEAR, RAC, TAC, CCCR, DEVSP, ENG, EN, PH2, MCCURS, TCOURS,
      MXT, MYM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, MDIST, MDIST,
      TURNT, INIVAL, PHI, RMAX(5,6), FRANGE, DIST, IPRINT
```

```
COMMON/DATA/TA, OFLOB
```

```
COMMON/TARGET/TACMG, TAM1, RANGMOD, DA1, COUR, CE(10), SE(15), JRUN,
      IFLAG, DA2
```

```
DIMENSION RM(5,5), VAR(5), DET(150,5), DETB(150,5), STD(5),
      ASPEC(150,5), DERB(150,5), CLOS(150,5), KON(150,5)
```

```
REAL LAMBE, MCOURS, MXT, MYM, MDIST, LAMBDG
```

```
INTEGER RUNOUT
```

SETTING OF CONSTANTS (STEP 1)

CALL OVFLW

```
PHI = 3.141592654
PH2 = 2.*PHI
RAD = PH2/360.
ISEED1 = 362776
ISEED2 = 961695
```

CCOREC - MAX ERROR IN TARGET COURSE ESTIMATE

```
CCOREC = 15.
CCOR = CCOREC * RAD
```

CSPEED - ST DEV IN TARGET SPEED ESTIMATE

```
CSPEED = 3.
DEVSP = CSPEED * 0.5
ITIME = 1
```

SET NUMBER OF ITERATIONS

```
JRUN = 150
```

(CONTINUED ON PAGE 2)

SET PRINT OUT MODE

```

      |-----|
      | IPRINT = 1 |
      |-----|

```

SET LCEE OFF TORPEDO CENTER BEARING

```

      |-----|
      | CFLOB=0. |
      |-----|

```

SET TABLES TO ZERO (STEP 2)

```

      |-----|
      | DO 11 |
      | I=1,5 |
      |-----|
      |
      | DO 12 |
      | J=1,5 |
      |-----|
      |
      | BM(I,J) = 0. |
      |-----|
      |
12  ++++++CCONTINUE
      |
11  ++++++CONTINUE
      |
      | DO 13 |
      | J=1,5 |
      |-----|
      |
      | DO 14 |
      | I=1, IEUN |
      |-----|
      |
      | KCN(I,J) = 0 |
      |-----|
      |
14  ++++++CCONTINUE
      |
13  ++++++CCONTINUE
      |
      | EA2 = 0. |
      |-----|

```

(CONTINUED ON PAGE 3)

COMPUTE TARGET ERRORS AND STORE

```

      DO
      I=1,10
      CE(I)=-{15.*RAD+CCOR/10.)*(CCOR
      /10.)*I*2.
      CONTINUE

```

```

      +-----+
      | DO          |
      | 900         |
      | JRUN=1,IJUN |
      +-----+
        |
    SET RUN COUNTERS (STEP 3)

    IFLAG=1; TOC LOW TORPEDO SPEED

      +-----+
      | IFLAG=0     |
      | ICCNT=0     |
      | JCONT=0     |
      | ITIME=0     |
      | IL   =C     |
      | IK    =0     |
      | DIST  =0.    |
      | MYT   =0.    |
      | MXM   =0.    |
      | SUNOUT=0     |
      +-----+
        |
(Continued on Page 4)

```


[illegible]

126


```

CALL DETECT

CHECK CPA(CLOSEST POINT OF APPROACH) (STEP 8)

      |
      |-----|
      | IL   =IL+1 |
      |-----|
      |
      |
      * . * IF * . *
      * . IL.LE.20 * . *
      * . * T | 500 |
      * . *
      * . * F
      * . *
      |
      |-----|
      | IL   =0 |
      | CPA  =LIST |
      |-----|
      |
      |
      * . * IF * . *
      * . CPA1-CPA.LE.0. * . *
      * . * T | RUNOUT=1 |
      * . *
      * . * F
      * . *
      |
      |-----|
      | CPA1 =CPA |
      |-----|
      |
      |-----|
      | 500 |
      |-----|

GENERATE STATISTICS (STEP 9)

CCCONTINUE
      |
      +-----+
      + DO          +
      + 910         +
      + IKL=1,5     +
      +-----+
      |
      |
      (CONTINUED ON PAGE 9)

```



```

      * . IF * .  

    * : IFLAG.EQ.1 * :  

    * . * . * . T | 991 |  

      F  

PRINT CUT (STEP 10)  

-----  

| COUR =MCOUFS/RAD  

| TC   =TCOURS/RAD  

| IT   =ITIME/2  

-----  

      F  

      * . IF * .  

    * : IPRINT.EQ.0 * :  

    * . * . * . T | 195 |  

      F  

***WRITE(6,252) JRUN,TACMG,TAM1,BNGXCD,DA1,COUR,XT,YT,XLAR,YLAR,  

IT,MXT  

FCBMT(1X,'/',1X,I3,3X,F5.1,2X,F4.1,1X,F6.0,2X,F5.1,3X,  

F5.1,7X,F6.0,1X,F6.0,2X,F6.0,1X,F6.0,3X,I4,2X,F6.0)  

      F  

      * . IF * .  

    * : BMAX(1,1).EQ.0. * :  

    * . * . * . T | 991 |  

      F  

      -----  

      | 9C0 |  

      -----  

195 ***WRITE(6,200) IT  

200 FCBMT(1X,'RUN STOPPED AFTER ',I5,' SECONDS',//,  

     1X,'RUN DATA AS FOLLOWS AT END OF RUN')  

(CONTINUED ON PAGE 11)
```



```

+-----+
+ DO      +
+ 28      +
+ LR=1, IEUN  +
+-----+
|
+-----+
+ RM(KR,1) = RM(KR,1) + FLOAT(KCN(LR,KR)) |
+ RM(KR,2) = RM(KR,2) + DET(LR,KR)       |
+ RM(KR,3) = RM(KR,3) + ABS(ASPEC(LR,KR)) |
+ RM(KR,4) = RM(KR,4) + DETS(LR,KR)      |
+ RM(KR,5) = RM(KR,5) + DERB(LR,KR)      |
+-----+
|
28 +++++++CONTINUE
27 +++++++CONTINUE
|
+-----+
+ DO      +
+ 920     +
+ KK=1, 5  +
+-----+
|
COMPUTING MEANS
|
+-----+
| DEL = SM(KK,1) |
+-----+
|
+-----+
+ * IF * |
+ * DEL.IE.1. * |
+ * * * * * |
+ * * * * * T | DEL=1. |
+ * * * * * |
+-----+
|
+-----+
+ RM(KK,2) = RM(KK,2)/DEL |
+ RM(KK,3) = RM(KK,3)/DEL |
+ RM(KK,4) = RM(KK,4)/DEL |
+ RM(KK,5) = RM(KK,5)/DEL |
+-----+
|
920 +++++++CONTINUE

```

(CONTINUED ON PAGE 13)

(CONTINUED ON PAGE 14)


```

+
+
+
++++++CCNINUE

```

```
PRINT SUMMARY (SIEF 13)
```

```
***WRITE(6,197)JRUN
```

```
197      FORMAT(1X,/,6X,'SUMMARY OF RESULT AFTER',3X,I4,2X,'RUNS')
```

```
***WRITE(6,199)((RM(I,J),J=1,2),STD(I),(RM(I,J),J=3,5),I=1,5)
```

```
199      FORMAT(10X,'FEASIBILITY OF DETECTION',3X,
     1 'AVERAGE',6X,'STD DEVIATION',7X,'AVERAGE',7X,'AVERAGE',
     2 7X,'AVERAGE',6X,41X,
     3 'DET RANGE',6X,'DET RANGE',7X,'TARGET ASPECT',4X,'DET BEARING',
     4 3X,'BEI BEARING',/,
     5 1X,'ONE SUCCESSIVE DETECTION',5X,F6.4,5(6X,F9.4),/,
     6 1X,'TWO SUCCESSIVE DETECTIONS',4X,F6.4,5(6X,F9.4),/,
     7 1X,'THREE SUCCESSIVE DETECTIONS',2X,F6.4,5(6X,F9.4),/,
     8 1X,'FOUR SUCCESSIVE DETECTIONS',3X,F6.4,5(6X,F9.4),/,
     9 1X,'FIVE SUCCESSIVE DETECTIONS',3X,F6.4,5(6X,F9.4),/)
```

```
220      FORMAT(1X,'NC DETECTION MADE DURING THIS RUN')
```

```
      | DA2 =DA2/NCAT(IRUN) |
```

```
***WRITE(6,190)DA2
```

```
190      FORMAT(1X,/,1X,'AVERAGE DEFLECTION ANGLE :',5X,F8.4,/)
```

```
***WRITE(6,234)
```

```
234      FORMAT(1X,/,1X,'DISTRIBUTION OF RUN RESULT - CENTER OF TARGET',/,
     1 6X,'ONE SUCCESSIVE DETECTION',10X,'TWO SUCCESSIVE DETECTIONS',/,
     2 8X,'THREE SUCCESSIVE DETECTIONS',/,
     3 2X,'BEAR',2X,'RANGE',ASPECT BEAR CLOS',6X,'BEAR',2X,
     4 'RANGE',ASPECT BEAR CLOS',5X,'BEAR',2X,
     5 'RANGE',ASPECT BEAR CLOS')
```

```
***WRITE(6,236)((DET(I,1),DET(I,1),ASPEC(I,1),CLOSB(I,1),
     1 DET(I,2),DET(I,2),ASPEC(I,2),CLOSB(I,2),DETS(I,3),
     2 DET(I,3),ASPEC(I,3),CLOSB(I,3)),I=1,IRUN)
```

```
236      FORMAT(3(1X,F6.1,1X,F6.1,1X,F6.1,2X,F6.1,5X))
```

```
999      STOP
```

```
END
```


A TORPEDO SIMULATION. SUBROUTINE PARMET.

SUBROUTINE PARMET

READING IN DATA AND PARAMETERS

COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBE, TADEC,
 BEAR, RAC, TAC, CCOR, DEVSP, BNG, EN, PH2, MCCURS, TCOURS,
 MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST,
 MDIST, TUENTO, INTVAL, PHI, RMAX(5,6), TRANGE, DIST, IPGINT
 REAL LAMBE, MCCURS, MXT, MXM, MDIST, LAMBDG
 INTEGER BUNCUT

TEDEC - TECHNICAL DETECTION RANGE (STEP A1)

LEVEL OF VARIATION: 375-750-1125-1500 METERS

TADEC - TACTICAL DETECTION RANGE

TEDEC=750.
TADEC=TEDEC

TTIME - TRANSMISSION INTERVAL

TTIME=2.*TEDEC/1500.

TCKN - TORP SPEED IN KNOTS, TO - TORP SPEED IN M/SEC (STEP A2)

LEVEL OF VARIATION: 24-32-40 KNOTS

TCKN = 40.
TO = TCKN/2

TAKN - TARGET SPEED IN KNOTS, TA - TARGET SPEED IN M/SEC (STEP A3)

LEVEL OF VARIATION: 12-18-24-30 KNOTS

TAKN = 18.
TA = TAKN/2

(CONTINUED ON PAGE 2)

TACG - TARGET COURSE IN DEGREE (STEP A4)

```
| TACG =270  
| TAC =TACG*RAD  
|
```

ALFAG - SWEEP ANGLE IN DEGREE, ALFA - SWEEP ANGLE IN RADIANS

(STEP A5)

LEVEL OF VARIATION: 20-30-40 DEGREES

```
| ALFAG=30.  
| ALFA =ALFAG*RAD  
|
```

LAMBDG - LOBE WIDTE EACH SIDE OF TORP HEADING (STEP A6)

LEVEL OF VARIATION: 10-20-30 DEGREES

```
| LAMBDG =20.  
| LAMED=LAMBDG*RAD  
|
```

BELEBG - RELATIVE BEARING FROM TARGET TO TORP IN DEGREE (STEP A7)

LEVEL OF VARIATION: 0-30-60-90-120-180 DEGREES

```
| BELEBG =-60.  
| BEAR =BELEBG*RAD  
|
```

RANGE - DISTANCE BETWEEN TARGET AND TORP (STEP A8)

LEVEL OF VARIATION: 1500-3000-5000-7000 METERS

```
| RANGE=3000.  
|
```

(CONTINUED ON PAGE 3)


```

      1
      ***WRITE(6,112) RANGE,BELBERG,TACG,TAKN,TEDEC,TOKN,ALFAG,
      LAMBEG,TRATEG,SRNG,CBATIO
112      FORMAT(1X,F6.0,2X,F6.1,3X,F5.1,3X,F4.1,6X,F6.1,3X,F5.1,3X,
      F4.1,3X,F4.1,2X,F4.1,2X,F6.1,3X,F5.3)
      1
      1 95 1

```

```

90      ***WRITE(6,100)
100      FORMAT(1X,'TACTICAL SITUATION WHEN FIRING',/,1X,
      'FIRING RANGE',3X,'ATTACK ANGLE',3X,
      'TARGET COURSE',2X,'TARGET SPEED')
      ***WRITE(6,102) RANGE,BELBERG,TACG,TAKN
102      FORMAT(1X,4(2X,F6.1,7X),/)
      ***WRITE(6,104)
104      FORMAT(1X,'TORPEDO PARAMETERS',/,1X,
      'TECH.DET.RANGE',2X,'TRANS.INT.VAL',2X,'TORP SPEED',3X,
      'SWEEP ANGLE')
      ***WRITE(6,106) TEDEC,TIME,TOKN,ALFAG
106      FORMAT(1X,2(2X,F7.2,7X),2(F6.1,7X),/)
      ***WRITE(6,108) LAMBEG,TRATEG
108      FORMAT(1X,'LOBE WIDTH',6X,'TURN RATE',/,
      3X,F6.1,10X,F6.1)
      ***WRITE(6,109) SRNG,CBATIO
109      FORMAT(1X,'THEORETICAL WIDTH OF TACTICAL SWEEP-LANE',F9.1,
      /,1X,'THEORETICAL COVERAGE RATIO',F9.4)
95      RETURN

```

END

1
A TORPEDO SIMULATION. SUBROUTINE FIRING.

SUBROUTINE FIRING

CALCULATE THE TORP DEFLECTION ANGLE, MAIN COURSE, FIRING COURSE
BASED ON ESTIMATE OF TARGET DATA (UNCERTAINTY)

DIMENSION U(2)

COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBD, TADEC,
BEAR, RAL, TAC, CCOB, DEWSP, BNG, EN, PH2, MCCURS, TCOURS,
MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, MDIST,
MDIST, TURNIC, INTVAL, PHI, BMAX(5,6), TRANGE, DIST, IPHINT

COMMON/DATA/LA, OFLOS

COMMON/TARGET/TACMG, TAM1, RNGMOD, DA1, COUR, CZ(10), SE(15), JRUN,
IFLAG, DA2

REAL LAMED, MCCURS, MXT, MXM, MDIST, LAMBDG

INTEGER BUNCUT

```

      |
      | EN      =-1
      | EP      =1.
      | KSPEED  =MOD( (JRUN-1), 15) +1
      | KCOURS  =IFIX( (JRUN-1)/15.) +1
      |

```

CALL GGUE(ISEED2, 2, U)

CALCULATE ESTIMATE OF TARGET COURSE (STEP 31)

19

```

      |
      | TACM =TAC+CZ(KCOURS)
      |

```

20

```

      |
      | LIFCO=TACM-TAC
      |

```

(CONTINUED ON PAGE 2)

* . * I_F * . *

* TACM.GE.FH2 * . *

* . * . *

T | TACM=TACM-PH2

|

* . * I_F * . *

* TACM.IT.O. * . *

* . * . *

T | TACM=PH2+TACM

|

CALCULATE EST OF TARGET SPEED (STEP B2)

$$TAM = TA + SE(KSPEED)$$

CALCULATE TORPEDO DEPLETION ANGLE (STEP B3)

1

1 ASP = EEAR-DIFCO

```

      * . * . * .
      * ASP.IT.-FHI *
      * . * . * .
      T | ASP=PH2+ASP
      F-----|
      IACS =TAM*SIN(ABS(ASF))
      LAA =IACS/IC

```

(CONTINUED ON PAGE 3)

$$RNGMOD = RANGE + SIGN(RNGDIF, PP)$$

```
TACMG=TACM/EAD
TAM1=TAM*2
LA1=LA/RAC
LA2=LA2+LA1
```

PRINT CUT OF FIRING DATA

IF
IPRINT.EC.1
T 1 25

```
***WRITE (6, 122) TACMG, IAM1, ENGMOD
```

```
122      FORMAT(1X,'EST OF TARGET DATA FOR FIRING',/,
            4X,'COURSE',5X,'SPEED',6X,'RANGE',/,
            1X,3(F8.1,3X))
```

***WRITE (6,124) LA1

```
124      FCFMAT(1X,'TCBF DEFLECTION ANGLE IS ',F6.2)
```

1 COUR = MCCUES/RAD

***WRIIE (6, 125) COUR

```
125      FCRMAT(1X,'TORPEDO MAIN COURSE',8X,F6.2)
```

126 CONTINUE

25

26 ***WRITE (6, IC)

30 FCEMAT (/ , 1X, 'NOT FEASIBLE TO FIRE DUE TO LOW TORPEDO SPEED')

```

| IFLAG= 1

```

25 RETURN

END

A TORPEDO SIMULATION. SUBROUTINE POSIS.

SUBROUTINE POSIS

IS CALCULATING NEW POSITIONS OF TARGET AND TORPEDO IN
EACH TIME STEP

COMMON ISEED2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMEL, TADEC,
BEAR, RAL, TAC, CCCR, DEVSP, ENG, EN, PH2, MCCURS, TCOURS,
MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, TDIST,
MDIST, TURNTO, INTVAL, PHI, RMAX(5,6), TRANGE, DIST, IPBINT
REAL LAMEL, MCCURS, MXT, MXM, MDIST, LAMBDG
INTEGER RUNCUT

TIME CCUNT (STEP C1)

```

      IK = IK + 1
      ITIME = ITIME + IDTIME

```

CALCULATE TOTAL TCRP RUN AND TARGET RUN (STEP C2)

```

      MXT = MXT + TDIST
      MXM = MXM + MDIST

```

CALCULATE NEW POSITIONS (STEP C3)

```

      XT = XT + SIN(TCOURS) * TDIST
      YT = YT + COS(TCOURS) * TDIST
      XTAR = XTAR + SIN(TAC) * MDIST
      YTAR = YTAR + COS(TAC) * MDIST

```

CALCULATE NEW TCRP COURSE (STEP C4)

```

      TXCOUR = TCOURS + SIGN(TURNTO, EN)
      TXCDIF = ABS(MCOURS - TXCOUR)

```

(CONTINUED ON PAGE 2)


```

      *   *   *   *   *
    *   IF   *   *   *
  * TXCDIF.GI.PHI *
  *               *
    *   *   *   *   *
      T       | TXCDIF=PH2-TXCDIF

```

TXCDIF.IF.ALFA

```

EN      =-EN
ALFADI  =TXCDIF-ALFA
TXCOUR  =TXCOUR+2.*SIGN(ALFADI,PN)

```

15

```

-----
| ICCURS =IXCCUR
-----

```

```

      * * * * *
      *   IF   *
      * TCOURS.GI.PH2 *
      * * * * *
      *-----*
      *          T | TCOURS=TCOURS-PH2

```

```
*      *      *
*      IF      *
TCOURS.IT.O.*
*-----*
```

25

RETURN

END

A TORPEDO SIMULATION. SUBROUTINE DETECT.

SUBROUTINE DETECT

TO CHECK IF TARGET IS DETECTED AND STORE DETECTION DATA

COMMON ISZEE2, TTIME, TO, TA, TRATE, RANGE, ALFA, LAMBE, TADEC,
SEAR, RAD, TAC, CCCF, DEVSP, BNG, EN, PH2, MCCURS, TCCURS,
MXT, MXM, IK, IDTIME, ITIME, XT, YT, XTAR, YTAR, IDIST,
MDIST, TUBENTC, INTVAL, PHI, RMAX(5,6), TRANGE, DIST, IPINT

COMMON/DATA/LA, OFLCE

REAL LAMEE, MCCURS, MXT, MXM, MDIST, LAMBDG

INTEGER RUNOUT

DIMENSION LB(3,2)

DOUBLE PRECISION PCWMAX,B,RBX,RBX1,RBX2,X1,X2,X3,XX1,
V1,V2,V,U,FIFACT,XC1,X02,X03,XX2,POWER,RELB,ALAM

SETTING OF TARGET DIMENSION, A - TARGET LENGTH,

B - TARGET WIDTH, C - TARGET DEPTH. (STEP D1)

A	=100.
B	=15.
C	=4.

CHECK IF TRANSMISSION (STEP D2)

IF	IK.LT.INTVAL	T	20
IK	=0		

(CONTINUED ON PAGE 2)

CALCULATE RANGE TO TARGET (STEP D3)

```

      DIPX = XTAR - XT
      DIPY = YTAR - YT
      DIST = SQRT ( (DIPX**2) + (DIPY**2) )

```

TEST IF TARGET IS WITHIN POSSIBLE DETECTION RANGE

```

      IF (DIST.GT. (TADEC+A/2.))

```

```

      T = 20

```

DETECTION THRESHOLD (STEP D4)

```

      POWMAX = 1. / (B*TADEC) **4
      U = SCALE (FHI/2.)
      CONST = (A**2) * (B**2) * (C**2)
      POWMAX = CONST * POWMAX * U

```

CALCULATE TIME TO TARGET (STEP D5)

```

      TIMDL1 = DIST / 1500.
      XTAR1 = XTAR + SIN (TAC) * (TIMDL1 * TA)
      YTAR1 = YTAR + COS (TAC) * (TIMDL1 * TA)

```

CENTE - BEARING OF CENTER OF LOBE (STEP D6)

```

      ED = -LA * CFLOB
      CENTB = TCCUES + DD

```

(CONTINUED ON PAGE 3)


```

      |
      |
      | * * * IF * * *
      | * RELA.GT.PHI * *
      | * * * * * T | RELA=PH2-RELA
      | * * * * *
      | * * * IF * * *
      | * RELA.LT.-PHI * *
      | * * * * * T | RELA=PH2+RELA
      | * * * * *
      |
      |-----|
      | RELE =AES (RELA)
      | V1  = (A**2) * (DCCS (RELB) **2)
      | V2  = (E**2) * (DSIN (RELB) **2)
      | V   = (V1+V2) **2
      |-----|
      |

```

COMPUTE SCALING FACTOR DUE TO ASPECT (STEP D11)

```

      |
      |-----|
      | U   =SCALE (RELB)
      | FIFACT =U/V
      |-----|
      |

```

CALCULATE RETURN TIME FOR ECHO (STEP D12)

```

      |
      |-----|
      | TIMDL2 =2.*TIMDL1
      |-----|
      |

```

CALCULATE REL BEARING FOR RETURNING ECHO (STEP D13)

```

      |
      |-----|
      | TURNST =TRATE*TIMDL2
      | TXC   =TCUBES+SIGN (TURNST,PN)
      | TXDC  =AES (MCCUBES-TXC)
      |-----|
      |

```

(CONTINUED ON PAGE 7)

TEST FOR DOPPLER

```

      FRQDEF = 50.*2.*(TO*CCS(DD)-1.)
      FRQDIF = 50.*2.*(TO*CCS(DD)+1.)
      FRQSH = 50.*2.*(TO*CCS(DD)+TA*CCS(RELC))

```

```

      IF (FRQSH.LT.FRQDIF).AND.(FRQSH.GT.FRQDEF)

```

T 20

CALCULATE RANGE AND BEARING TO CLOSEST PART OF TARGET (STEP D14)

```

      LB(1,1) = DIST
      LB(1,2) = REIT0+DD
      LB(2,1) = DIST1
      LB(2,2) = REIT1+DD
      LB(3,1) = DIST2
      LB(3,2) = REIT2+DD
      LMIN = LB(1,1)
      MD = 1

```

```

      IF LMIN.GT.LB(2,1)

```

T 10

9

```

      IF LMIN.GT.LB(3,1)

```

T 11

(CONTINUE ON PAGE 10)

CALCULATE FRACTION OF POWER IN TO RECIEVER (STEP D16)

```

      POWER=CCNST*Y11*XX2*FIPACT/(DIST
      **4)

```

TEST FOR DETECTION THRESHOLD (STEP D17)

```

      IF (POWER.LT.PCWMAX) THEN
        T = 15
      ELSE
        T = 0
      END IF

```

COMPUTE BEARING RATE (STEP D18)

```

      ASP = BE+PHI-TAC

```

```

      IF (ASP.GT.PHI) THEN
        T = ASP-ASP-PH2
      ELSE
        T = 0
      END IF

```

```

      IF (ASP.LT.-PHI) THEN
        T = PH2+ASP
      ELSE
        T = 0
      END IF

```

```

      AP = ASP*RELTO

```

(CONTINUED ON PAGE 12)


```

TACS=TA*SIN(AES(ASP))
-----
| TOCS=TC*SIN(ABS(RELT0))
| ERATE=(TACS+SIGN(TOCS,AP))/DIST
|
-----

```

CHECK BEARING RATE AGAINST TURNRATE (STEP D19)

```

      *
      * IF *
      * ERATE.GT. IRATE *
      * * * * *
      * * * * * T | 15 |
      * * * * *
      *
      * F
      *

```

CHECK TORPEDO SPEED ADVANTAGE (STEP D20)

```

-----
| TALS=TA*CCS(ABS(ASF))
| TOLS=TC*CCS(ABS(RELT0))
|
-----

```

```

      *
      * IF *
      * AES(ASP).GT.PHI/2. *
      * * * * *
      * * * * * T | TALS=-TALS
      * * * * *
      *
      * F
      *

```

```

      *
      * IF *
      * AES(RELT0).GT.PHI/2. *
      * * * * *
      * * * * * T | TOLS=-TOLS
      * * * * *
      *
      * F
      *

```

(CONTINUED ON PAGE 13)


```

      |
      |
      | * * *
      | * IF *
      | * (TALS+TCIS).LE.0: *
      | * * * * *
      | * * * * * T | 15 |
      | * * * * *
      |
      |

```

```

      |
      |-----|
      | RLB =RE-MCCURS |
      |-----|
      |

```

```

      |
      | * * *
      | * IF *
      | * RLB.GT.PHI *
      | * * * * *
      | * * * * * T | RLB=RLB-PH2
      | * * * * *
      |
      |-----|
      |

```

```

      |
      | * * *
      | * IF *
      | * RLB.LT.-PHI *
      | * * * * *
      | * * * * * T | RLB=PH2+RLB
      | * * * * *
      |
      |-----|
      |

```

STORE DETECTION DATA (STEP D21)

```

      |
      |-----|
      | JCONT=JCONT+1 |
      | JMAX =M10(JMAX,JCONT) |
      | ICONT=JCONT |
      |-----|
      |

```

(CONTINUED ON PAGE 14)


```
      * .  
    IF  
    ICONI.GE.5  
      T | ICONT=5
```

```
25      GO TO (30,31,32,33,34), ICONT
```

30

```
*      *      IF      *
*      BMAX(1,1).NE.0.*
*      *      *      T      | 20 |
*      *      F
-----
| FMAX(1,1) =DIST
FMAX(1,2) =(RELTG+DD)/RAD
|
|
*      *      IF      *
*      BMAX(1,2).GT.180.*
*      *      *      T      | BMAX(1,2)=BMAX(1,2)-360.
*      *      *
|
|
-----
| BMAX(1,3) =DMIN
BMAX(1,4) =BBEL/RAD
BMAX(1,5) =BELA/RAD
BMAX(1,6) =BLE/RAD
|
|
| 20 |
```

(CONTINUED ON PAGE 15)

A TORPEDO SIMULATION. FUNCTION XFACT.

PAGE 1

A TORPEDO SIMULATION. FUNCTION XFACT.

FUNCTION IFACI(X,Y)

CALCULATE REDUCTION-FACTOR IN TRANSDUCER GAIN DUE
TO RELATIVE BEARING OFF CENTER-HEADING OF TORPEDO

DOEELZ PRECISICN X,XFACT,XY,Y

PHI = 3.141592654

IF
X.EQ.0.
T 10

XY = X/Y
XFACT = DABS((DCOS(X*0.5)*DSIN(XY
*PHI)))/(XY*PHI)

RETURN

10

XFACT = 1.

RETURN

END

PAGE 1

FUNCTION SCALE (Y)

COMPUTING TARGET STRENGTH

PHI = 3.151592654

```

      *   *   *
    .   .   .
  *   IF   *   *
Y.GT.PHI/2. *
*   *   *   *
          T   | Y=PHI-Y
              |
F-----|

```

```
Z = 0.251635*(Y**2)-0.18555*Y
Z = Z+0.0365*DSIN(3.*(Y+0.17453))
+0.015*(Y**2)*DSIN(9.*Y/2.)
SCALE=1./Z
```

RETURN

END

APPENDIX C

DETAILED RUN PRINTOUT

TACTICAL SITUATION WHEN FIRING

FIRING RANGE 3000.0 ATTACK ANGLE -50.0 TARGET COURSE 270.0 TARGET SPEED 15.0

TORPEDO PARAMETERS

TECH. DET. RANGE 750.00 TRANSL. INT. VAL 1.00 TORP SPEED 40.0 GUESS ANGLE 50.0

LOSSE WIDTH TURN RATE

20.0 0.0

THEORETICAL WIDTH OF TACTICAL SWEEP-LANE 1149.1

THEORETICAL COVERAGE RATIO 0.8500

SONAR MAIN LOSSE OFF-SET FROM CENTER BEARING 0.0 TIMES DEFLECTION ANGLE

RUN NUMBER : 1

EST OF TARGET DATA FOR FIRING

COURSE SPEED RANGE
250.5 12.4 3345.1

TORP DEFLECTION ANGLE 10 -12.07

TORPEDO MAIN COURSE 17.03

RUN STOPPED AFTER 150 SECONDS

RUN DATA AS FOLLOWS AT END OF RUN

TOTAL TORP RUN 2750.0

DIST TO TARGET 515.0

TORP X-COORD 14274.5 TORP Y-COORD 14089.0

TARGET X-COORD 13771.5 TARGET Y-COORD 15000.0

TORP MAIN COURSE 17.027 TORP COURSE 357.025

NO DETECTION MADE DURING THIS RUN

RUN NUMBER : 2

EST OF TARGET DATA FOR FIRING

COURSE SPEED RANGE
250.5 14.2 2702.4

TORP DEFLECTION ANGLE 10 -14.87

TORPEDO MAIN COURSE 15.13

RUN STOPPED AFTER 147 SECONDS

RUN DATA AS FOLLOWS AT END OF RUN

TOTAL TORP RUN 2242.0

DIST TO TARGET 681.1

TORP X-COORD 14250.7 TORP Y-COORD 15000.0

TARGET X-COORD 13677.0 TARGET Y-COORD 15000.0

TORP MAIN COURSE 15.120 TORP COURSE 11.500

MAXIMUM DETECTION RANGES AND BEARINGS

SUCCESSIVE DET	MAX RANGE	DET - CENTER CENTER	DET BEARING CENTER	MAX DET RANGE - CLOSEST	DET BEARING CLOSEST	TARGET ASPECT
1	502.5		5.17	550.5	10.20	-07.50
2	545.8		-1.40	530.5	5.00	-00.50
3	0.0		0.0	0.0	0.0	0.0
4	0.0		0.0	0.0	0.0	0.0
5	0.0		0.0	0.0	0.0	0.0

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